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TECHNICAL REPORT M-284
March 1981
New Roofing Concepts in the Military Construction Process

AN EVALUATION OF POLYVINYL CHLORIDE (PVC) SINGLE-PLY MEMBRANE ROOFING SYSTEMS

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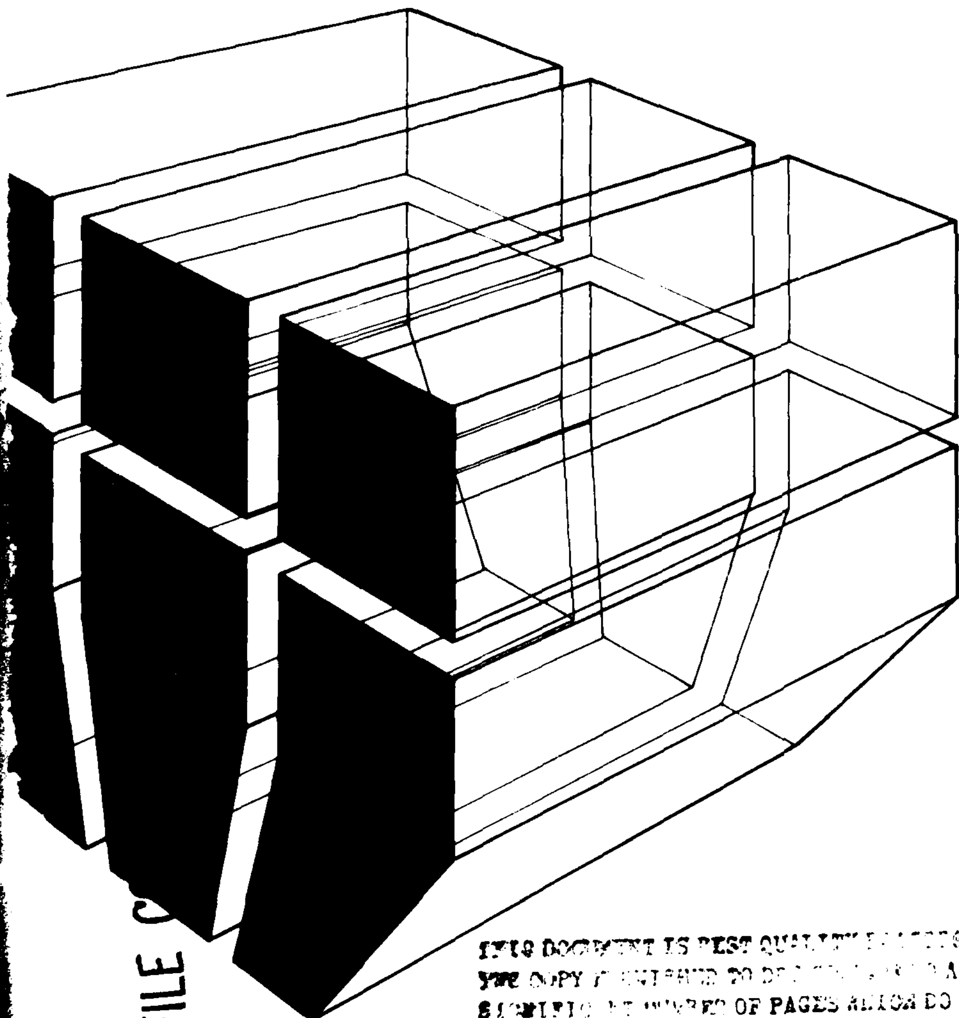

by
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This report documents a study to evaluate polyvinyl chloride (PVC) single-ply membrane roofing systems and materials for use at Army installations.

It was found that PVC single-ply membranes can be used as an alternative to conventional built-up roofing (BUR) for new roofs or to reroof failed

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roofs. However, because PVC systems are relatively new and long-term durability statistics are not available, they should only be used on carefully selected Army roofs.

The two most serious PVC membrane problems identified during the study were:

1. Embrittlement caused by plasticizer loss or by exposure to ultraviolet rays,

2. Excessive shrinkage.

It was concluded that these problems can be minimized by using reinforced PVC membranes and by using manufacturer-improved ultraviolet- and evaporation-resistant membranes.

FOREWORD

This investigation was performed for the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under Project 4A762731AT41, "Military Facilities Engineering Technology"; Task A, "Military Construction"; Work Unit 044, "New Roofing Concepts in the Military Construction Process." The OCE Technical Monitor is J. Ichter, DAEN-MPE-S.

The work was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. E. L. Marvin. Dr. G. R. Williamson is Chief of EM.

COL Louis J. Circeo is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

Most Army facilities use conventional roofing systems, such as built-up roofing (BUR), that are sometimes expensive and complicated to construct. These conventional roofing systems are often also comparatively short-lived, resulting in high life-cycle roofing costs which are difficult for already overburdened Army operation and maintenance budgets to absorb. Therefore, the Directorate of Military Programs has asked the U.S. Army Construction Engineering Research Laboratory (CERL) to attempt to identify alternative, easy-to-install roofing systems that can improve the performance of Army roofing while reducing life-cycle costs.

Objective

The overall objective of CERL's roofing studies is to (1) evaluate innovative roofing systems and materials to determine alternatives to BUR systems, (2) provide a means to improve Army roof performance and reduce life-cycle costs, and (3) develop guide specifications for selected alternative systems.

The specific objective of this report is to document an investigation into the use of one alternative material, polyvinyl chloride (PVC).

Approach

This investigation is being conducted in the following steps:

1. Survey of literature, manufacturers, and field applications to identify advantages, disadvantages, benefits, and problems associated with the use of PVC membranes.

2. Construction of PVC membrane roofs at selected Army installations.

3. Evaluation of the design, construction, and post-construction performance of the test roofs over a period of 2 years.

4. Determination of the suitability of PVC for use in Army roofing systems and the possible subsequent development of a guide specification.

This report documents Step 1, above.

Mode of Technology Transfer

If the results of this study show that PVC roofing can be used at Army installations, a Guide Specification for the use of PVC membrane roofing will be included in the Corps of Engineers Guide Specification series 07000.

2 DEVELOPMENT OF PVC AS A ROOFING MEMBRANE

History

The use of PVC for roofing originated in Europe, where the first PVC roof was installed in 1955.[1] Several manufacturers have entered the field since then, and new PVC roofs can be found in all climates from Saudi Arabia and Uganda to Spitzbergen, Norway. One of the first successful PVC roofs was installed in the continental United States in 1971. It was built by Trocal in the Paterson, NJ area on a high-rise apartment building. About 10,000 sq ft (929 m^2) were installed (loose-laid and ballasted) on board insulation above the old BUR. Originally all PVC roofing membranes were manufactured in Europe, but at least two manufacturers now produce the material in this country.

Manufacture

In its raw state, PVC is a hard, brittle solid. Before PVC can be used as roofing material, it must be formulated with softening materials called plasticizers which alter its physical and mechanical properties. Some plasticizers result in a material which is still a hard solid, but which is no longer brittle. The most common uses of this form of PVC are vinyl siding for residences and water and waste piping. Other plasticizers create a soft, pliable material which is used for clothing and furniture upholstery.

The plasticizers used for roofing membranes must result in a material which is firm but resilient, elastomeric, nonvolatile, and able to withstand long-term exposure to ultraviolet radiation and severe changes in weather.

Depending on its manufacturer, PVC sheets are available in widths from 48 to 80 in. (1219 to 2032 mm), thicknesses from 32 to 60 mils (0.81 to 1.51 mm) and lengths from 65 to 150 ft (20 to 45 m). There are three basic methods of producing these sheets: calendering, extruding, and spread coating.

1. Calendering is a process by which a formless mass of PVC is progressively reduced in thickness and increased in width by passing it between successive pairs of rolls. Because of the effects inherent in calendering, it is necessary that the resulting single thickness be no more than 32 mils (0.88 mm). Thicker sheets produced by the calender process must be laminated from at least two thin sheets.

2. Extruding is a process in which the softened, hot PVC is forced through a die of the proper size and shape to produce the desired product immediately.

3. Spread coating is a process in which a loose-woven or felted reinforcing fabric is spread on both sides with soft, hot PVC and heat-cured into one integral sheet.

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[1] "Singling Out the Single-Ply," Roofing, Siding, Insulation, Vol 54, No. 11 (November 1977), p 62.

Reinforcing material can be calendered into a laminated sheet but not inserted into an extruded one.

Properties

To be successful as a roofing membrane, PVC must retain its properties over a wide range of temperatures and other ambient conditions; i.e., it should remain resilient and elastomeric from subarctic to subtropic climates, and be able to withstand long exposure to sunlight, water, snow, and ice. It should have enough tensile strength so that when the membrane shrinks, it will not tear away from its fastenings. It should also have elasticity to prevent the build-up of excessive tensile stresses. Its plasticizers should evaporate slowly enough to allow the material to retain its resilient and elastomeric properties for many years. It should also be easy to make permanent, watertight membrane seams in the field. The membrane should permit the passage of water vapor, but not liquid water, and should resist attack by common chemicals and solvents. The completed roof should meet Factory Mutual and Underwriters' Laboratories fire safety requirements.

The physical and mechanical properties of some of the PVC sheeting currently on the market for use as roof membranes are listed in Table 1. (The manufacturers contacted during this investigation did not all list the same properties in the same units and did not use the same test methods for all the determinations. However, Table 1 compares all PVC properties on the same basis to allow an engineering evaluation of the different materials.)

Table 1

Comparison of Physical and Mechanical Properties*

Company	Dynamit Nobel		Sarnafil		USM Weathershield			USM Weathershield			VCP	Water Guidance			
Trade Name	Trocal		Sarnafil		Flexhide			Braas Rhenofol			VCP	Plyroof			
Thickness (mils)	48	60	47	47	34	45	50	35	35	48	40	32	32	45	45
Reinforcement	None	None	Glass	polyester	none	none	polyester	none	polyester	polyester	none	none	nylon	none	nylon
Weight (lb/sq ft)	0.3	0.39	0.33	0.27	0.23	0.30	0.32	0.24	0.22	0.29	0.258	0.21	0.20	0.29	0.27
Width of sheet (ft)	(2)	5'-11"	6'-6 11/16"	4'-11"	6'-10"	6'-0"	6'-0"	6'-8 3/8"	6'-8 3/8"	6'-8 3/8"	4'-0"	5'-0"	4'-6"	4'-0"	4'-6"
Length of sheet (ft)	(2)	65	65.5	98.4	75	75	75	65.6	65.6	65.6	150	100	100	100	100
Tensile strength (psi) (D638/D882)	2500	2844	1420	2380	2800	2330	1900	2500	1700	2000	2375	2000	175(6)	2000	225(6)
Seam strength (psi) (D638/D882)	(2)	(2)	(1)	(1)	2800(3)	2330(3)	1900(3)	2500(3)	1700(3)	2000(3)	2240	(1)	(1)	(1)	(1)
Elongation (%) (D638/D882)	405	250	250	25	400	400	255	320	270	245	375	250	175(6)	250	175(6)
Tear resistance (lb/in.) (D1004)	18.4	680	(1)	(1)	348	350	409	345	335	410	420	250	MD ‡ 10, CMD ‡ -20	300	MD ‡ 10(6), CMD ‡ -20
Shrinkage (%)(D1204)	(2)	(2)	0	0.5	2.0	2.0	0.5	3.0	<0.5	0.5	(1)	3.0	3.0	3.0	3.0
Shore A hardness (D2240)	84	82	85	85	85	85	85	74	76	69	77	75	(1)	75	(1)
Permeance, perm (E96,A)	2400	(2)	0.44	0.44	0.23(3)	0.20(3)	0.14(3)	0.23	0.12	0.14	(1)	0.73	0.73	0.73	0.73
Heat Aging, TS (D573)	395	(2)	(1)	(1)	(1)	(1)	(1)	1900	1700	1700	(1)	1600	140	1600	180
Heat Aging, elong (D573)	(2)	(2)	(1)	(1)	(1)	(1)	(1)	270	270	260	(1)	200	140	200	140
Low temperature impact (D1790) 50% failure (°F)	-50	(2)	(1)	(1)	-25	-25	-20	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Volatility (%)(D1203)	(2)	(2)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	0.9	(1)	(1)	(1)	(1)
Flame spread (ft)(E108)	(2)	(2)	(1)	(1)	0(5)	0(5)	5 to 11(4)	0(5)	0(5)	6 1/2	(1)	(1)	(1)	(1)	(1)

(1) information not available
(2) Manufacturer would not release information
(3) estimate from different test method
(4) varies with type of insulation and slope
(5) tested with ballast over membrane
(6) Testing Coated Materials, ASTM D 751-73 (American Society for Testing and Materials [ASTM], 1973).

3 CHARACTERISTICS OF PVC ROOFING MEMBRANES

Advantages

Because PVC roofing membranes are single-ply, they have several advantages over traditional BUR systems.[2]

1. Light weight. The traditional BUR with aggregate cover weighs about 6 lb/sq ft (30 kg/m^2), not including insulation. An unballasted single-ply PVC membrane roof weighs less than 1 lb/sq ft (5 kg/m^2).

2. Adaptable. PVC systems can be used on almost any roof slope or substrate material, including architecturally prominent roofs.

3. High elasticity. PVC systems can elongate to bridge cracks in the substrate and accommodate both thermally and structurally induced movement. In many cases, membrane expansion joints are not necessary.

4. Good reflectivity.

5. Easy to install. PVC systems generally require less effort to install than traditional BUR systems; application is cleaner, cooler, and requires smaller crews.

6. Easy to repair. Reroofing or repairing PVC single-ply membranes is relatively easy and sometimes can be done without entirely removing the underlying system. Small punctures are easy to patch by cementing a new piece over the hole.

7. Easy to insulate. PVC systems allow insulation to be readily added to existing buildings.

8. Compatible. PVC membranes are chemically inert to many commonly encountered environments; exceptions are discussed in Chapter 5.

9. Immune to shortages. An asphalt shortage caused by a scarcity of petroleum will not affect the use of PVC roofing systems, as little or no asphalt is used in PVC installation.

10. Easy to flash and seal. PVC allows intersections with vertical walls, parapets, and roof penetrations to be easily flashed and sealed with adhesives and roofing accessories.

11. Vapor permeability. Although PVC roofing membranes permit the ready passage of water vapor, thus allowing the roof to "breathe," they are impermeable to liquid water.

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[2] E. Marvin, et al., Evaluation of Alternative Reroofing Systems, Interim Report (IR) M-263/ADA071578 (U.S. Army Construction Engineering Research Laboratory [CERL], June 1979).

Disadvantages[3]

1. Small safety factor. Sheet-applied systems offer only a small safety factor, since a single membrane layer will almost certainly allow any puncture or failure to cause leakage. Therefore, the success of these systems depends on competent workmanship which assures that the membrane is properly sealed.

2. Lack of dimensional stability. Some membrane materials are not dimensionally stable. This can cause the membrane to shrink and separate from seams or flashings.

3. Inadequate operational statistics. While PVC systems have been used in Europe for about 15 years and in the United States for about 9 years, there has not been enough time to ascertain PVC performance when compared with the 80-year history of BUR systems. Also, material changes occur frequently, and a product purchased today may not resemble its counterpart purchased 5 or 10 years ago.

4. Lack of performance and design criteria. As a result of limited exposure and a wide variety of formulations in use, there are no real standards by which to judge PVC roofing systems. The design parameters which must be controlled to ensure proper performance are not well known. The only industry standard currently in use which even approximates the required properties is ASTM D 3083, which standardizes the requirements for PVC pond, canal, and reservoir linings.[4] The maximum thickness described in this specification is 30 mils (0.76 mm), while all roofing membranes made are thicker, ranging up to twice this figure. The allowable shrinkage of 5 percent is too high for use as a roofing membrane, the resistance to soil burial is not important, and no determination is made of the effects of exposure to ultraviolet radiation.

PVC Failure -- Causes and Case Histories

No one material can meet all roofing needs; PVC is no exception. Certain restrictions on its use are recognized by the manufacturers; others are deduced from familiarity with PVC's characteristics. (Data on membrane, other components, and workmanship-related failure given below were provided to CERL by Sarnafil, Inc.)

Membrane Failures

1. The methods used in the manufacture of PVC membranes can cause the membranes to shrink after they are applied. Calendered and extruded membranes are created with inherent stresses caused when their molecular structure is reorganized by the heat used in the manufacturing process. When exposed to solar radiation (i.e., after being applied to a roof), solar heat gain causes

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[3] The information in this section was taken from E. Marvin, et al., Evaluation of Alternative Reroofing Systems, IR M-263/ADA071578 (CERL, June 1979).

[4] Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal and Reservoir Lining, ASTM D 3083 (American Society for Testing and Materials [ASTM], 1976).

yet another molecular restructuring. This effect can be observed at the membrane's perimeters and terminations; i.e., the membrane may actually tear away from its attachments, causing the roofing system to fail.

2. Reinforcing material has been used to add dimensional stability and strength to PVC membranes. It is not easy, however, to reinforce a membrane which is calendered or extruded unless the membrane materials are laminated to the reinforcing materials. Therefore, it is possible that the membrane will delaminate after it is installed and exposed to the various stresses of weather and aging.

3. PVC membranes are subject to plasticizer migration and volatilization. These occur as the membrane ages or when it comes in contact with certain incompatible materials. Plasticizer migration and volatilization can embrittle the membrane; the resulting flexibility loss can seriously damage the roofing system.

Failures Related to Other Components in the Roofing System

1. With increased heating costs and the current emphasis on fuel economy, almost all roofing projects use thermal insulation. The choice of which insulation to use must be made with the roofing membrane in mind. Material incompatibility must be avoided; PVC materials <u>cannot</u> be used if they will come into direct contact with any asphaltic or bituminous materials, so any insulation which has an asphalt-impregnated skin may not be used. Polystyrene insulation also may not be used, since it rapidly extracts the plasticizers from the membrane, causing it to become brittle. In addition, uncured polystyrene insulation has a high shrinkage rate; even in loose-laid and ballasted applications, ballast weight plus solar radiation can cause an unadhered membrane to stick to the polystyrene insulation. Shrinkage under these conditions can create serious problems; i.e., the membrane may be pulled away from the intersections of vertical and horizontal surfaces.

2. When thermal insulation is mechanically fastened to the deck, the uplift resistance of the entire roofing assembly depends on the quality of the fasteners and the pattern of the nailing. Fasteners with sharp-cornered plates or nails which protrude above the surface of the insulation board can puncture PVC membranes.

3. In fully adhered applications, the ways the insulation is bonded to the deck and the membrane are critical to the uplift resistance of the system. It is equally critical that the insulation have enough interlaminar strength to withstand wind uplift forces. Delamination may cause the entire roofing assembly to blow off the roof.

Failures Related to Workmanship

All overlap seams are made by the roofing contractor on the job site (unless the roof is prefabricated) using the sealing method required by the manufacturer. If the quality of the seam is poor, a roofing failure may occur. The manufacturer's specifications <u>must</u> be followed; failure to follow manufacturer's specifications or use of "short-cut" methods can cause the roof to fail. Materials must be stored properly onsite in a dry and asphalt-free environment.

Failure Experience in the United States

This study considered several cases of PVC roof failure. In one case, a group of PVC membranes split where they joined metallic base flashings because of stress caused by shrinkage and plasticizer loss. This splitting occurred as workmen walked on the roofs during routine inspection; when cuts were made along the flashings to relieve the stresses, the membranes continued to tear, but at an angle to the flashings. The manufacturer recovered the buildings with new PVC material, which was placed directly over that which had failed.[5] In another case, failure occurred during construction on a large warehouse in Freeport, ME, in January 1979. When the temperatures fell to 0°F (-18°C) or below, an area about 1/6 of the total PVC membrane (about 25,000 sq ft [2320 m^2]), shattered like glass when any object was dropped on it. However, only one lot number of the shipment had this problem; the balance of the material was flexible even at low temperatures. The manufacturer replaced the defective material at no cost to the contractor for either material or labor.[6]

Failure Experience in Europe

A contractor in Switzerland has reported negative experience with PVC roofing installations.[7] From 1969 to 1976, he applied between 40 and 50 PVC single-ply installations using 32 mil (0.81 mm) unreinforced sheets. This contractor stopped installing single-ply systems in 1976. All single-ply systems installed by this contractor before then were having problems, most of them after 2-1/2 to 3 years. The PVC used was not resistant to ultraviolet. After exposure to the elements, the sheet changed to a brown color, became hard and brittle, and began to split. Splits occurred even where the sheet was covered with ballast. On some installations, the sheet shrank 7 to 17 percent. On one application, leaks resulted from insect perforations.

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[5] Personal communication between CERL and American Telephone and Telegraph Co., 21 January 1980.

[6] Personal communication between CERL and James A. McBrady, Inc., South Portland, ME, 21 February 1980.

[7] Preliminary Report on Single-Ply Systems (Midwest Roofing Contractors Association, June 1978).

4 INSTALLATION METHODS

Details of the installation methods described in this chapter are in Appendix A.

Loose Laid

The simplest way to install PVC membrane roofing is to lay it loosely on top of the substrate. The membrane is attached only around the perimeter of the roof and at any penetrations which may exist. Depending on the design, insulation may be installed either below or above the membrane. The insulation does not need to be fastened in place, as the roofing system is ballasted to resist wind uplift. The weight of this ballast is normally 10 lb/sq ft (50 kg/m^2), which is heavy enough for most locations. The ballast material is either well-rounded, water-washed gravel 3/4 to 1-1/2 in. (19 to 38 mm) in size (which corresponds to size No. 4 in ASTM C 33)[8] or concrete pavers of the proper thickness to provide the necessary weight.

The loose-laid concept allows the roofing membrane and the structure to move independently. It has the following major benefits:

1. Cracking caused by wrinkling, blistering, and splitting is eliminated.

2. The high weathering resistance provides a maintenance-free system with a long service life.

3. The membrane can be installed in almost any weather.

4. Installation costs compare favorably with those of a conventional BUR system.

5. The membrane can be prefabricated in large segments offsite, thus reducing or even eliminating the need for field seaming.

6. Because of its permeability, the membrane can be installed over damp substrates. In winter, loose snow can be swept off the substrate, but the surface does not need to be completely snow-free. As the moisture evaporates, the vapors will pass through the membrane. A ventilated installation will accelerate this process.

7. The membrane may be applied on roofs with slopes up to 1 to 12.[9]

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[8] Specification for Concrete Aggregates, ASTM C 33 (ASTM, 1978).
[9] E. Marvin, et al., Evaluation of Alternative Reroofing Systems, IR M-263/ADA071578 (CERL, June 1979).

Partial Bonding

This method uses elements of both the loose-laid and fully bonded systems. A number of round plates are firmly fastened to the substrate by mechanical means in a predetermined pattern and spacing. The membrane is then bonded to this pattern. Insulation or other board material beneath the membrane must also be firmly fastened or adhered to the substrate.

Partial bonding is well suited to reroofing projects where the old roofing is not removed, as very little weight is added to the structure. In addition to many of the benefits of the loose-laid system, partial bonding:

1. Has a low dead load.

2. Transfers wind uplift forces to the structural deck.

3. Can be applied on almost any slope, and where a ballasted system cannot be applied.

4. Eliminates extra weight because ballast is unnecessary.

Full Bonding

This method fully fastens the roofing system to the roof deck. Like the partially bonded system, it is well suited to reroofing projects where the old roofing is not removed. It also can be used on steep roofs where ballast cannot be retained and where partial bonding will allow the membrane to sag between fastening points.

For full bonding, a layer of hardboard or insulation must first be mechanically fastened to the deck, since PVC is incompatible with asphalt or coal tar. For application above a BUR from which only the loose gravel has been removed, an impermeable separation layer must first be firmly adhered to the BUR. The roofing membrane is then applied using a contact cement.

5 USING PVC SYSTEMS

Reroofing

About 85 percent of the single-ply PVC roofing installed in the continental United States is used to reroof failed BUR systems. Single-ply PVC systems are good BUR replacements because, in many cases, it is not necessary to remove the old BUR. It is sufficient to sweep off the loose gravel and apply new insulation and a PVC membrane. If the roof deck is strong enough to bear the added dead load, the membrane can be loose-laid and ballasted. If not, then the membrane can be partially or fully bonded, depending on (1) the type of deck, (2) the moisture content of the existing system, (3) the ease of ventilation, and (4) the slope of the roof. Installing a single-ply membrane without removing the old system uses much less labor than if the old BUR has to be removed.

The manufacturers of single-ply systems all claim that it is unnecessary to remove the old roof, that even a saturated system will eventually dry out. As their reasons, they cite the permeability of the membrane, which will allow the passage of water vapor but not liquid. Much caution should be taken in considering this method of reroofing.[10] A deteriorated BUR above saturated or excessively wet insulation constitutes an unacceptable substrate. The effectiveness of vents in relieving this condition has not been determined by technical studies, and lateral migration of moisture to the roof edge is extremely slow, if not questionable. If the BUR contains blisters or cracks, these should be repaired. The reroofing work should be put on as flat a base as possible. Most or all of the deficiencies of the substrates should also be corrected or removed.

Wood fiber board should not be used between old, wet BUR and a new PVC membrane. The moisture from the wet insulation and BUR membrane will migrate into the fiber board and cause it to deteriorate before it can be vented out of the system to the atmosphere.

New Construction[11]

About 15 percent of the single-ply PVC now used in the continental United States is used for new construction. However, the amount of all types of single-ply elastomeric sheet roofing installed is only about 10 percent of the total roofing work being performed. One reason for this is that "The big built-up roofing companies never really went after the re-roofing market. If you look around, you see that new construction is bituminous roofing. But even that will eventually change as the price of bituminous materials goes up and the big property owners in the country switch to single-ply roofing."

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[10] W. J. Rossiter, Jr., and R. G. Mathey, Elastomeric Roofing: A Survey, National Bureau of Standards (NBS) Technical Note 972 (U.S. Department of Commerce, NBS, July 1978).

[11] All data and quotations in this section are based on information in "Unraveling the Mystery of Single-Ply Roofing Systems," Roofing, Siding, Insulation, Vol 56, No. 8 (August 1979), p 36.

The relative cost of a single-ply system as compared to a BUR system is an important consideration. As an average, the single-ply system costs about 10 percent more than BUR, but there are certain tradeoffs:

1. If the roof is on a very high building, it is difficult to deliver the hot bitumen and to maintain it at the proper temperature. Because single-ply sheets are easier to handle, the overall labor cost should be lower.

2. On a large flat roof, built-up material is less expensive, but with the passage of time, the prices will balance out as both labor and materials costs increase.

3. The initial cost of installation is less for a BUR, but in 3 or 4 years, maintenance costs on a BUR will even out this difference. In 8 to 10 years, a BUR will cost about one-third more than a relatively maintenance-free single-ply roof.

Flashing and Sealing

Flat Vertical Surfaces and Roof Edges

There is no industry-wide standard for flashing PVC roof membranes against walls, parapets, or curbs. The two common methods in use are:

1. PVC-coated sheet metal is extended up the vertical surface and out onto the roof (with or without a canted portion). The roof membrane is then solvent-welded to the sheet metal.

2. The roof membrane is extended up the vertical surface to whatever termination is necessary. All PVC manufacturers recommend either one or the other method (depending on the application).

All PVC manufacturers supply sheet metal coated on one side and painted on the other. The PVC coating serves two purposes: it provides a PVC surface to which the membrane sheet can be welded, and protects the metal (usually galvanized steel) from corrosion. Because the membrane tends to shrink, the manufacturers require that the horizontal flange be mechanically fastened to a wood nailer especially installed for that purpose. Specified pullout strengths vary from 75 to 175 lb-force/ft (1095 to 2560 N/m), depending on the individual manufacturer's specifications. Expansion joints in the sheet metal are usually made by leaving a gap between ends of the sections, covering the gap with tape or kraft paper as a slip sheet, and then solvent-welding a wider piece of PVC roof membrane to cover the joint. There may or may not be a backing plate (another piece of coated sheet metal) beneath the flashing. As the roof membrane is welded on top of this strip and the sheet metal flange, careful attention must be given to preparing and sealing the junction where all these surfaces meet. The edge of the sheet metal where the roof membrane is attached is usually a sheared edge. Even though the direction of shearing is down, there is the possibility that this edge will be sharp. However, none of the manufacturers recommends that this edge be turned under to provide a rounded finish before the membrane is attached.

In five of the installations observed during this investigation, the attachment of the coated sheet metal to the roofing membrane was deficient. The horizontal flange of the sheet metal was elevated above the surface of the substrate, which also raised the membrane. The space between the flange and the substrate could not be measured, but was estimated to be from 1/4 to 1/2 in. (6.35 to 12.7 mm). It appeared that the sheet metal flange was improperly fastened or not fastened. Tension from the shrinking membrane had pulled it up and away. It is possible that the insulation had shrunk until its surface was below the surface of the nailer, thus leaving the air space below the membrane. However, this was unlikely, as the sheet metal itself had apparently been raised from its original position. This problem was seen on roofs of two different manufacturers. It is possible that this defect is inherent in the PVC single-ply system. It may also be the result of improper installation. If the problem was caused by insulation shrinkage, then the wrong insulating material was used. Insulation boards must be dimensionally stable, and in most cases, must also be approved by the membrane manufacturer (see the next section of this chapter for a more complete discussion).

Corners

There is no industry standard for sheet metal flashing corners. Some manufacturers provide premolded PVC covers for inside and outside corners. Others tell the contractor to overlap the sheet metal and seal with sealant. In either case, the corner must be flashed very carefully if the joint is to be waterproof.

Pipes and Conduits

Unlike manufacturers of other types of single-ply roofing, manufacturers of PVC roofing do not furnish prefabricated pipe sleeves for flashing plumbing vents and other pipes which penetrate the roof. Pipe flashing with PVC is basically a two-piece installation. A flat flange piece of membrane is fitted around the pipe, rising up the pipe for a short distance like a collar. Another piece is then wrapped around and cemented to the pipe. This piece is solvent-welded to the flange piece. Seams are then sealed with a sealant. One manufacturer is more explicit than the others in the instructions for installing the flange piece. This manufacturer recommends cutting a hole one-fourth to one-third smaller in diameter than the pipe and then pulling this down over the pipe so that the collar is formed. Other manufacturers merely show the assembly in their details, leaving the procedure to the installer.

Seams

PVC is a thermoplastic material that (1) dissolves in certain solvents, and (2) softens and even melts at elevated temperatures. Both of these properties are used to form seams when PVC sheets are joined. All manufacturers specify a minimum seam lap; some manufacturers use mostly solvent to weld the laps. This solvent can be put on either by hand (with a paint brush) or with a special applicator machine. In either case, the seam is pressed with a roller to expel any entrapped air and to weld the two surfaces together.

Another way to seal PVC seams is to heat weld them. When a seam is heat-welded, hot air is blown through a special nozzle; the nozzle is drawn

between the sheets being joined, and the seam is pressed together with a roller. After the seams are welded, they are checked by drawing a probe along the exposed edge. Unsealed areas, called fishmouths, are heated, pressed together again, and rechecked.

PVC manufacturers claim that solvent welding allows PVC sheets to be joined at temperatures as low as -15°F (-26°C). Although theoretically possible, this is impractical, as both solvent and sheet will have to be preheated. Such low temperatures would also mean uncomfortable working conditions. A more practical low temperature limit would be 15 to 20°F (-10 to -7°C) at low wind velocities. One manufacturer recommends preheating below 40°F (4°C).

Joints between PVC membranes and all flashings are usually solvent-welded and rolled. After all seams have been probed and completed as necessary, all edges of all lap joints are then sealed with an extruded bead of a PVC preparation. This preparation is applied from a cartridge with a caulking gun. When it cures, it forms an integral part of the joint and provides a waterproof assembly.

Insulation Restrictions

Most manufacturers list the types of insulation approved for their systems. Some cannot be used with PVC if the PVC and the insulation will be in direct contact. The manufacturers allow for this by requiring a separation layer between insulation and membrane. All manufacturers require that insulation boards be rigid and dimensionally stable and have low thermal expansion coefficients. A brief summary of PVC insulation requirements is in Table 2.

Compatibility Restrictions

When considering a PVC roofing system, the designer must find out whether the PVC membrane will react with the other materials on the roof. For example, common roof materials like asphalt and coal-tar pitch cannot come in contact with PVC single-ply roofing. If they do, they can cause the PVC membrane to fail (see Chapter 3). All PVC roofing manufacturers stress that the membrane must be completely isolated from any contact with bituminous materials, especially coal-tar pitch. Water run-off from a coal-tar pitch roof can destroy a PVC membrane; even the fumes from coal-tar must be avoided. Bituminous materials have the effect of leaching the plasticizers out of the PVC, leaving it weak and brittle. An interesting demonstration of the effect of bitumen on PVC sheet was reported by Oliensis, who described the long-term effects of an experiment in 1970.[12] A sheet of PVC was kept in contact with plastic cement more than 2 years. The plastic cement leached the plasticizers from the PVC and the cement was softened to the point where rain washed it away; the cement did not harden as it normally does.

Another material whose compatibility with PVC must be carefully considered is the treatment used for wood blocking and nailers. Only waterborne

[12] G. L. Oliensis, "Contact Incompatibilities Between Bitumens and Polymers," The Roofing Spec, Vol 5, No. 4 (July 1977), p 20.

wood preservatives must be used. The treatment should comply with American Wood Preservers Bureau (AWPB) Standard LP-2.[13]

Polystyrene insulation must not come in direct contact with PVC, since it also can rapidly extract the plasticizers from the membrane. Either an impervious slip sheet between polystyrene insulation and the membrane or a composite board of a 1/2-inch (13-mm) layer of vegetable fiber board bonded to the polystyrene should be used.

Table 2

Comparison of Insulation Recommendations*

Type of Insulation Board	Dynamit Nobel	Sarnafil	USM Weathershield	VCP	Water Guidance
Glass foam	A	S	N	A	N
Glass fiber	A	A	A	N	N
Perlite	A	A	A	N	N
Urethane foam	A	A	A	A	N
Polystyrene	I	S	S	A	N
Composite	A	A	N	N	N
Other	I	I	I	I	N

A Approved for use
S Approved for use but requires a separation sheet
I Requires written approval and instructions from manufacturer
N Information not given in published literature
* Although recommendations are readily available from all manufacturers on specific request, only information published in catalogs or brochures is listed in this table.

[13] Standard for Softwood, Lumber, Timber and Plywood Pressure Treated With Water-Borne Preservatives for Above Ground Use, Standard AWPB LP-2 (American Wood Preservers Bureau, July 1971).

6 RESULTS OF SITE VISITS

Eight site visits were made to observe existing PVC single-ply membrane roofs and to photograph installation of one of them (Table 3). One roof, a Water Guidance product, was installed in 1978 at the New Orleans International Airport. It is in excellent condition, and has required no maintenance to the present time (April 1980).*

The sites visited are listed in Table 3. Sites 1 through 5 had the flashing and sealing deficiency described in Chapter 4; i.e., the flange of the sheet metal flashing had pulled up and away from the substrate. All roofs were loose-laid and ballasted systems. Since more than one manufacturer was involved, it can be deduced that the problem is inherent in the system, and not restricted to any one brand.

Site 7 was installed between light snows. Because the weather was not warm enough to melt the snow, the snow was brushed off the substrate. Both the insulation and membrane were laid loose. The completed roof was ballasted with standard-sized gravel. (No material was placed nor seams welded unless the ambient temperature was above $20^{\circ}F$ [$-7^{\circ}C$].)

Sites 2 and 5 had much water ponding. The ponded areas of Site 2 were properly drained. These ponds were very shallow and were draining slowly. The ponded area of Site 5 was a clerestory above the dining area of a barracks building. It had no drains, scuppers, gutters or any other means of removing water. The gravel stops on all four sides served as excellent dams, and the roof seemed to be dished with at least 3 in. (76 mm) of water. Neither location had any leaks. It should be noted, though, that the older of these roofs was only 2-1/2 years old at the time of inspection, which may not be enough time for any leaks to develop.

A summary of each site visit is in Appendix B.

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* For a complete discussion of the New Orleans International Airport roof, see E. Marvin, et al., Evaluation of Alternative Reroofing Systems, IR M-263/ADA071578 (CERL, June 1979).

Table 3

PVC Single-Ply Membrane Roofs Inspected

Site No.	Location	Owner	Make	Date Installed	New or Reroof	Type	Date Visited
1	Champaign, IL	Eisner Foods	Trocal	1977	Reroof	Loose & ballast	Nov 79
2	Urbana, IL	Carle Hosp.	Trocal	1977	New	Loose & ballast	Oct 79
3	Urbana, IL	Carle Hosp.	Trocal	1977	Reroof	Loose & ballast	Oct 79
4	Danville, IL	Hyster Corp.	Braas	1978	Reroof	Loose & ballast	Nov 79
5	Otis AFB, MA	U.S. Coast Guard	Braas	1978	Reroof	Loose & ballast	Dec 79
6	Claremont, NH	Marson's Dept Store	Sarnafil	1975	Reroof	Fully adhered	Jan 80
7	Champaign, IL	Univ of Ill Credit Union	Trocal	1980	New (Under Constr)	Loose & ballast	Feb 80
8	New Orleans, LA	Int. Airport	Water Guidance	1978	Reroof	Loose & ballast	Jan 79

7 CONCLUSIONS

1. Short-term experience indicates that PVC single-ply membranes can be used to install new roofs or to reroof failed roofs.

2. The lack of long-term experience, coupled with the failures reported in Switzerland and the United States, indicate that extreme caution should be used in determining the suitability of PVC single-ply membrane roofing for Army use. This determination may be made in two ways: (1) verify manufacturers' claims for the properties of their materials by independent Government testing and (2) develop a test specification and install several roofs for testing, preferably as part of scheduled re-roofing projects at Army installations, at various locations in CONUS.

3. The two most serious PVC membrane problems are embrittlement from loss of plasticizer or from exposure to ultraviolet rays and excessive shrinkage. Membrane shrinkage and embrittlement caused by plasticizer loss can be minimized by using reinforced PVC membranes and by using manufacturer-improved ultraviolet- and evaporation-resistant membranes.

REFERENCES

Marvin, E., et al., Evaluation of Alternative Reroofing Systems, Interim Report (IR) M-263/ADA071578 (U.S. Army Construction Engineering Research Laboratory, June 1979).

Oliensis, G. L., "Contact Incompatibilities Between Bitumens and Polymers," The Roofing Spec, Vol 5, No. 4 (July 1977), p 20.

Preliminary Report on Single-Ply Systems, (Midwest Roofing Contractors Association [MRCA], June 1978).

Rossiter, W. J., Jr., and R. G. Mathey, Elastomeric Roofing: A Survey, National Bureau of Standards (NBS) Technical Note 972 (U.S. Department of Commerce, NBS, July 1978).

"Singling Out the Single-Ply," Roofing, Siding, Insulation, Vol 54, No. 11 (November 1977), p 62.

Specification for Concrete Aggregates, ASTM C 33 (ASTM, 1978).

Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal and Reservoir Lining, ASTM D 3083 (American Society for Testing and Materials [ASTM], 1976).

Standard for Softwood, Lumber, Timber and Plywood Pressure Treated with Water-Borne Preservatives for Above Ground Use, Standard AWPB LP-2 (American Wood Preservers Bureau [AWPB], July 1971).

Testing Coated Materials, ASTM D 751 (ASTM, 1973).

"Unraveling the Mystery of Single-Ply Roofing Systems," Roofing, Siding, Insulation, Vol 56, No. 8 (August 1979), p 36.

APPENDIX A:

MANUFACTURERS' DETAILS

This appendix reproduces standard PVC membrane details published by four of the five manufacturers surveyed during this investigation. These drawings have been reduced in size and grouped onto common pages so they can be compared. Dynamit Nobel, USM Weathershield, and Water Guidance use PVC-covered sheet metal for most or all of their base flashings. Sarnafil relies almost exclusively on PVC membrane material as base flashing, and only occasionally uses coated sheet metal. Shrinkage does not seem to be a problem with the Sarnafil system, because the membrane is reinforced with glass or polyester fibers (see Table 1); shrinkage is 0.5 percent or less.

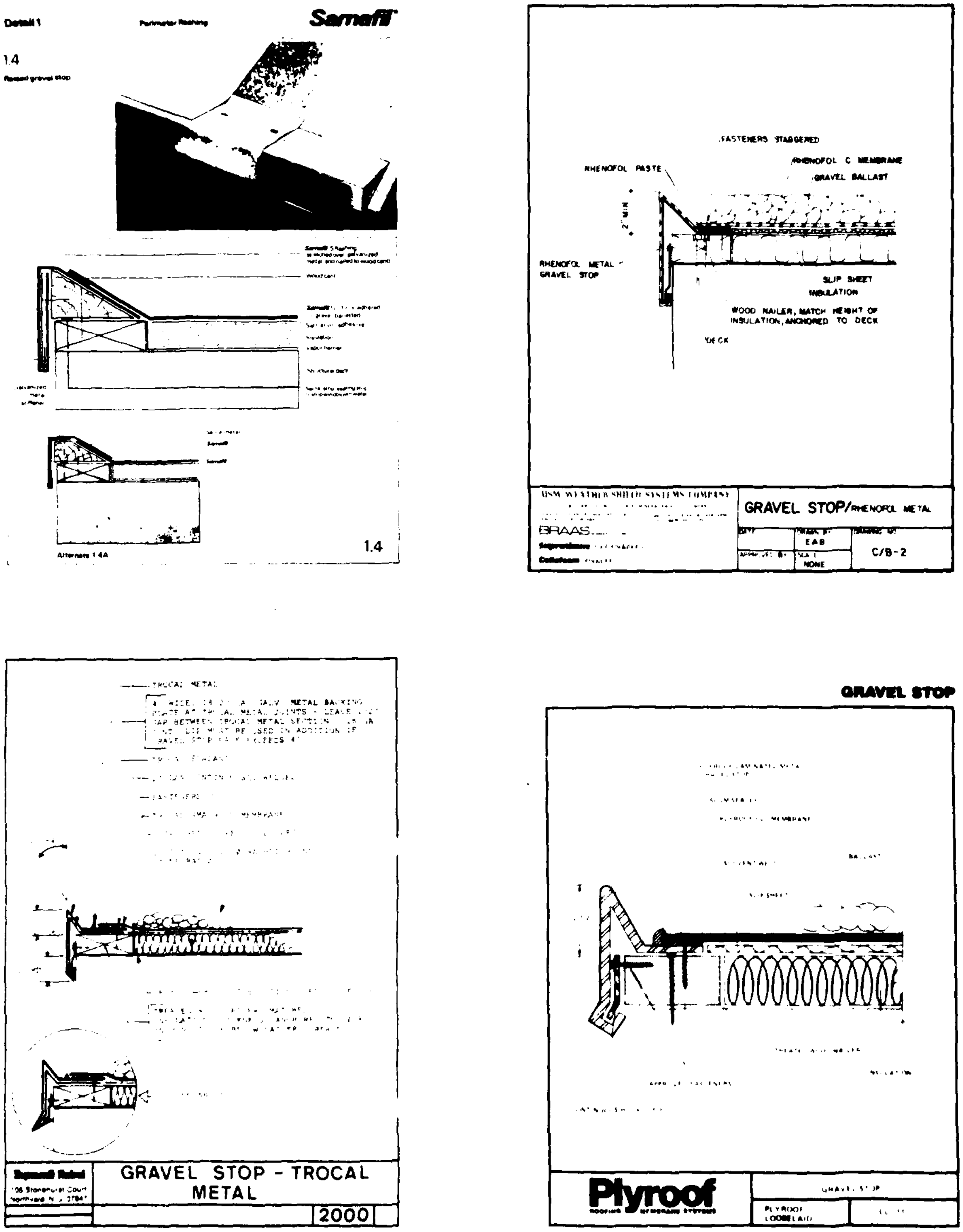


Figure A1. Typical gravel stops.

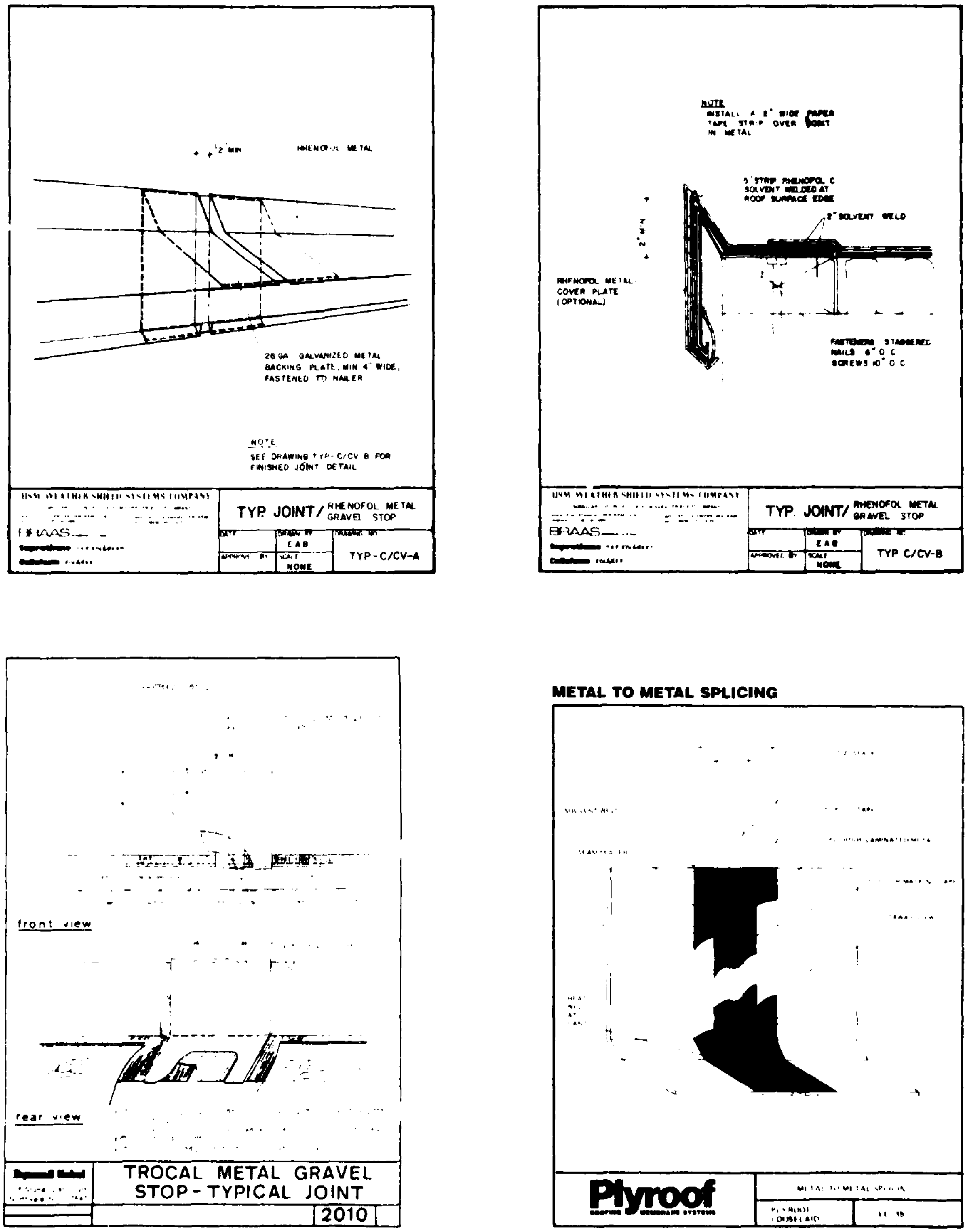
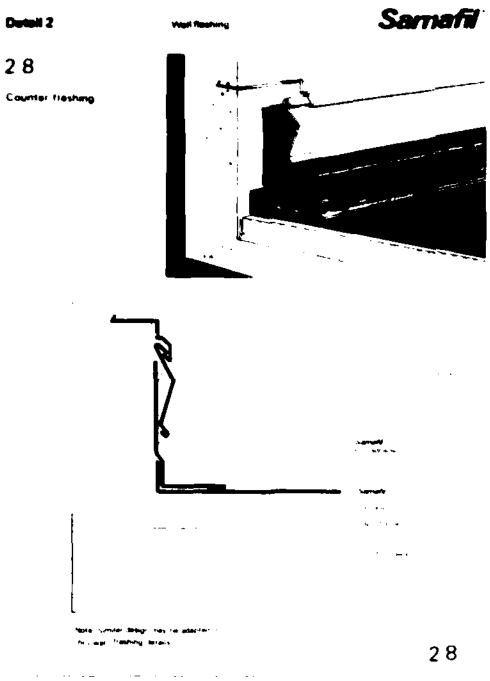
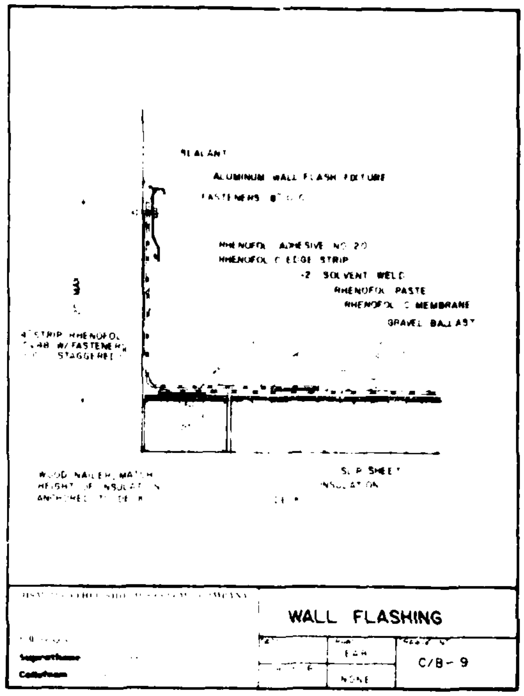
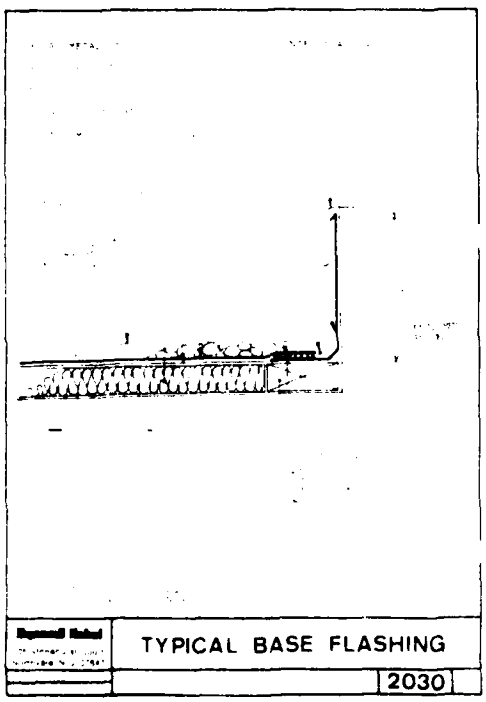


Figure A2. Joints in gravel stops.







WALL FLASHING DETAIL

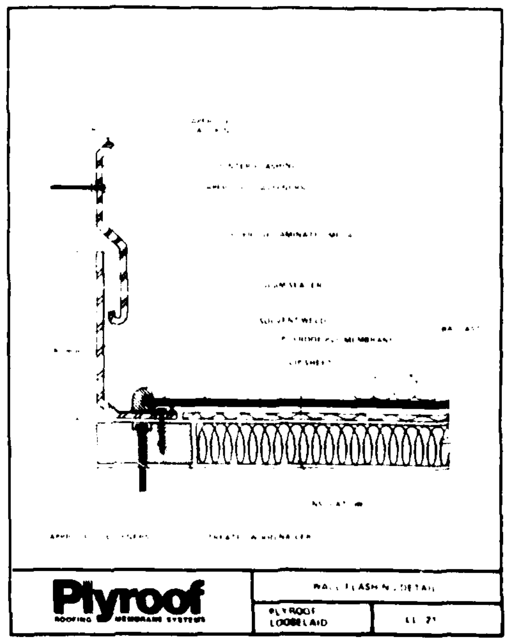
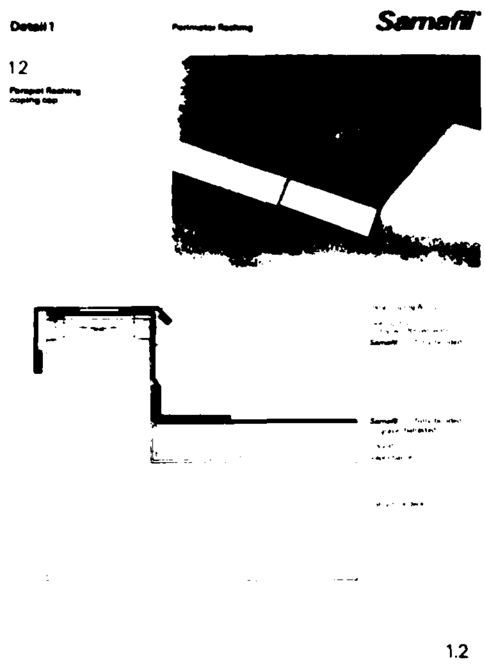
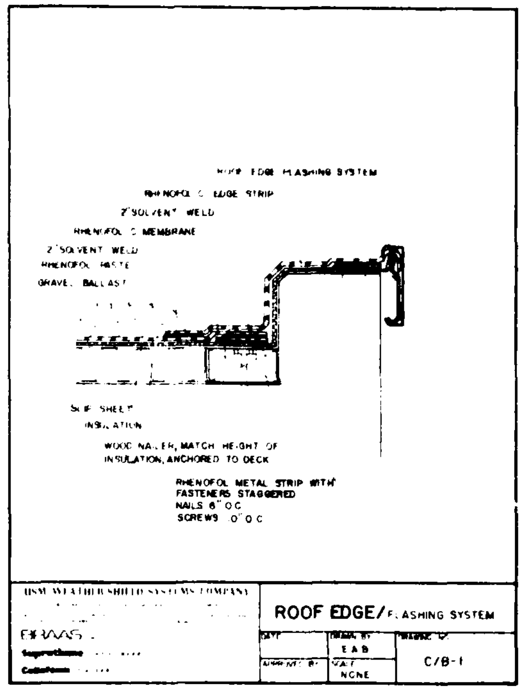
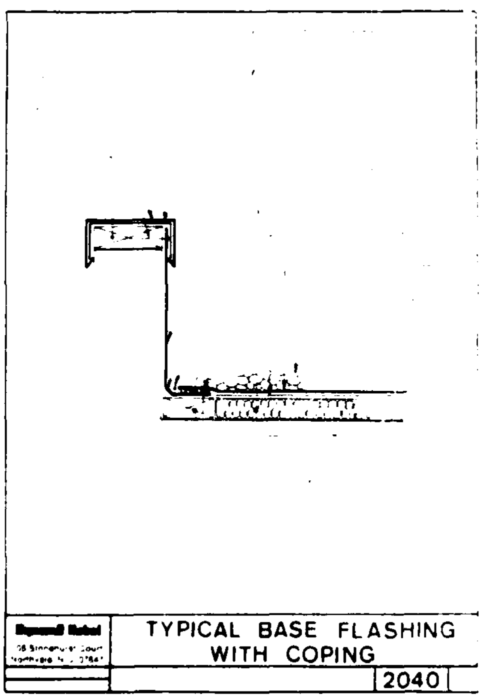


Figure A3. Base flashings at walls.







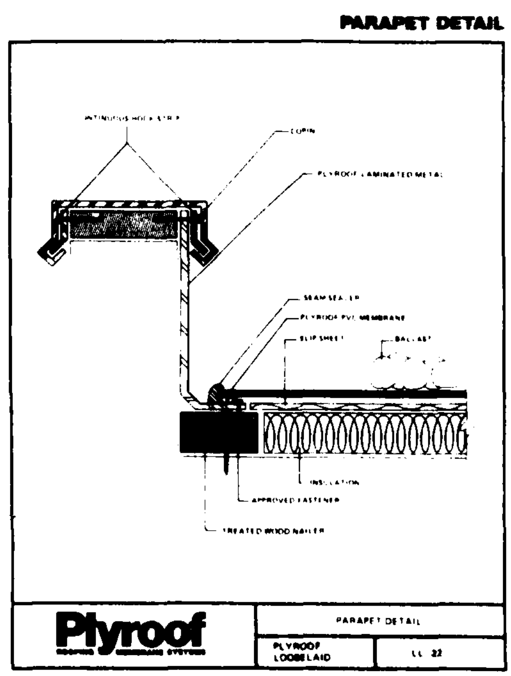
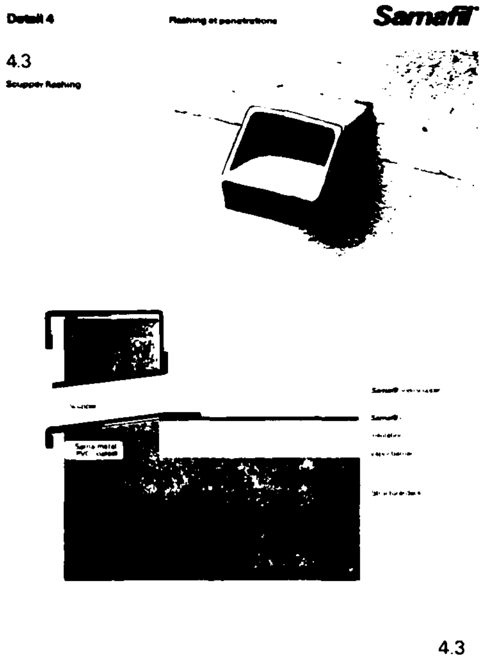
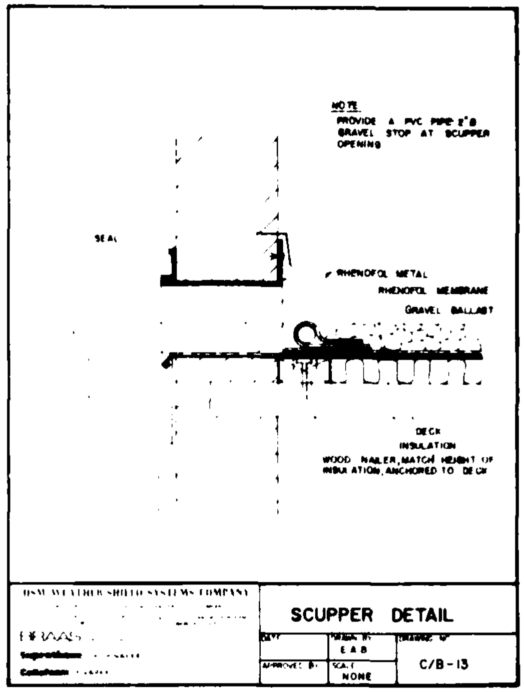
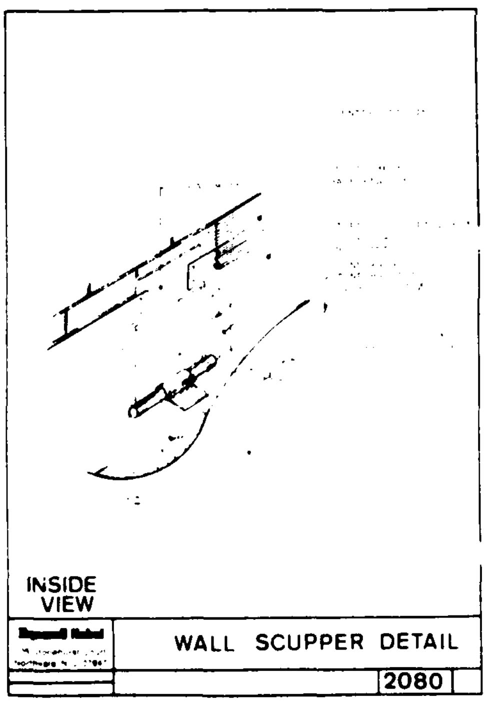


Figure A4. Base flashings at parapets.







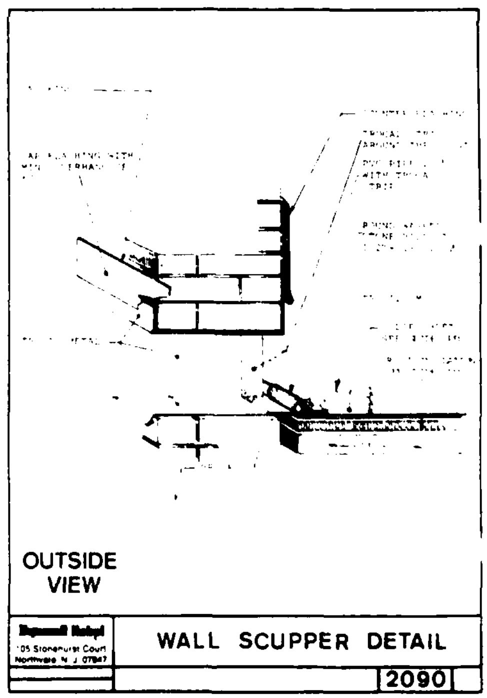
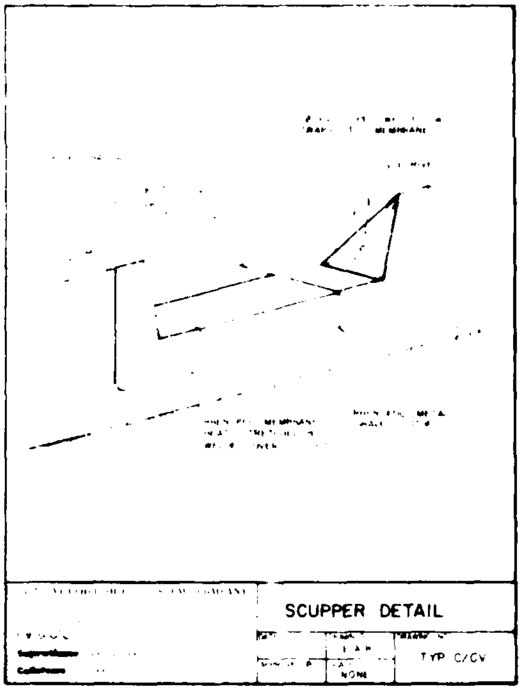
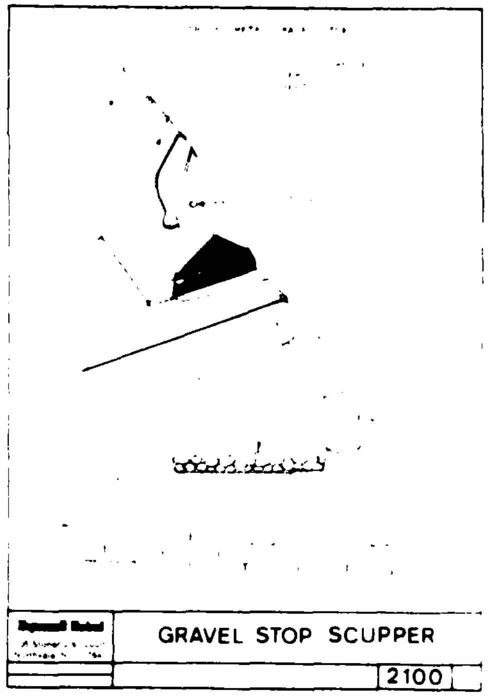


Figure A5. Wall scuppers.





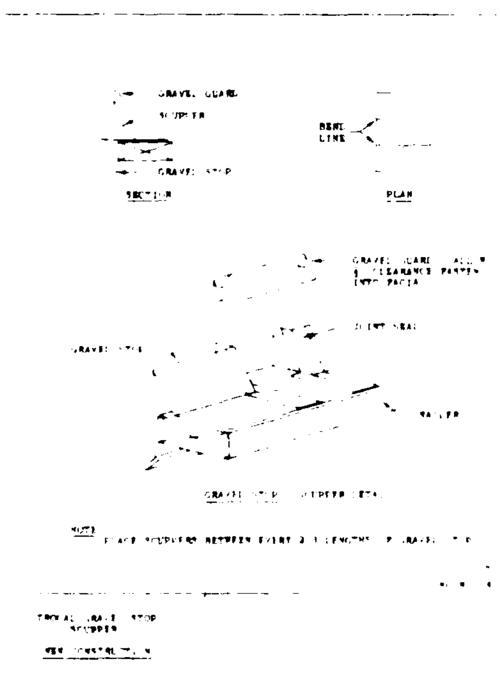


Figure A6. Gravel stop scuppers.

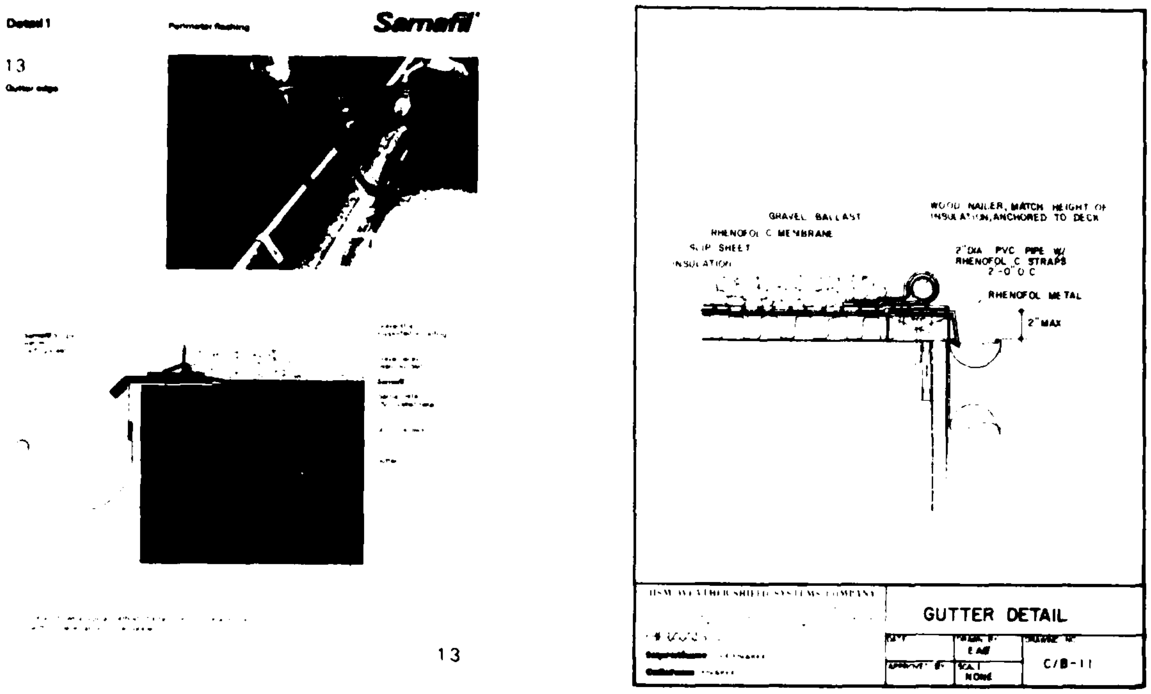


Figure A7. Gutters.

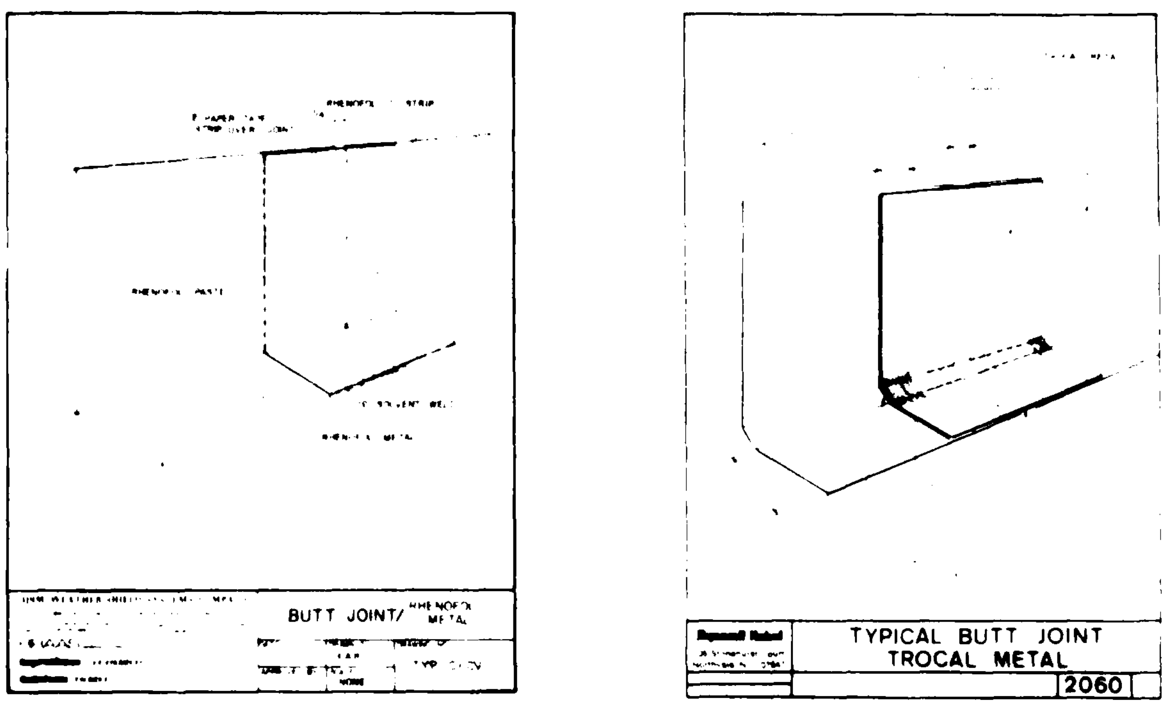
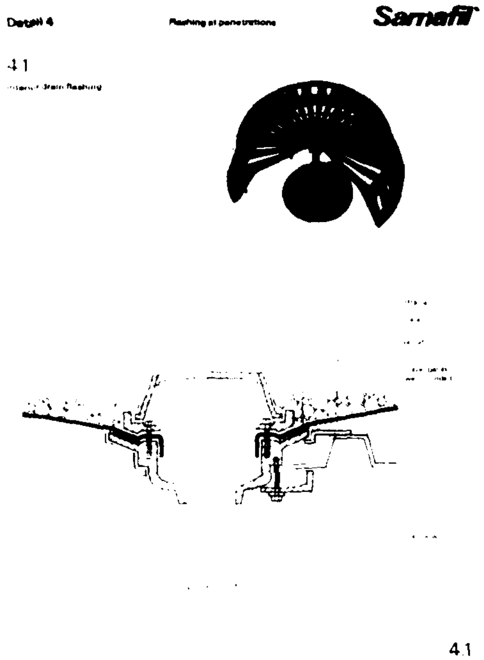
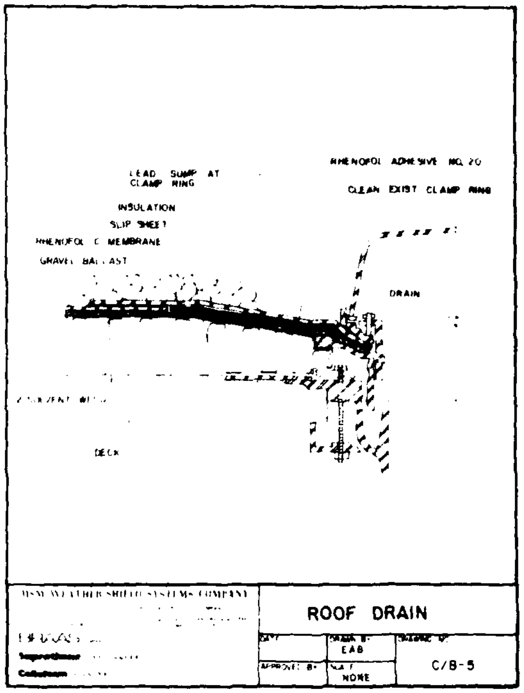
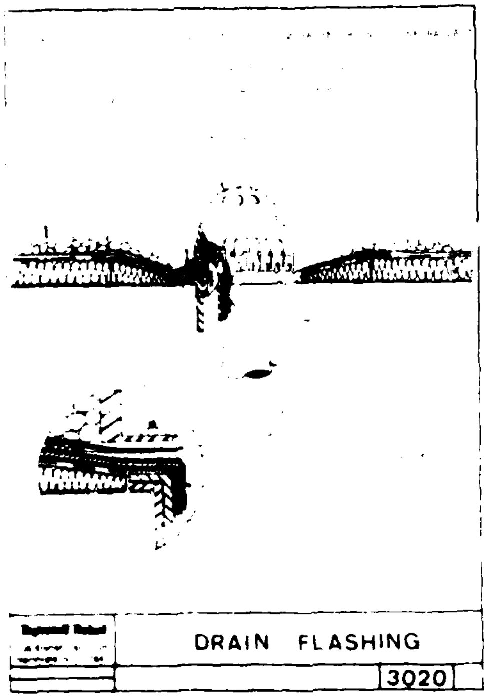


Figure A8. Typical butt joints.







ROOF DRAIN FLASHING

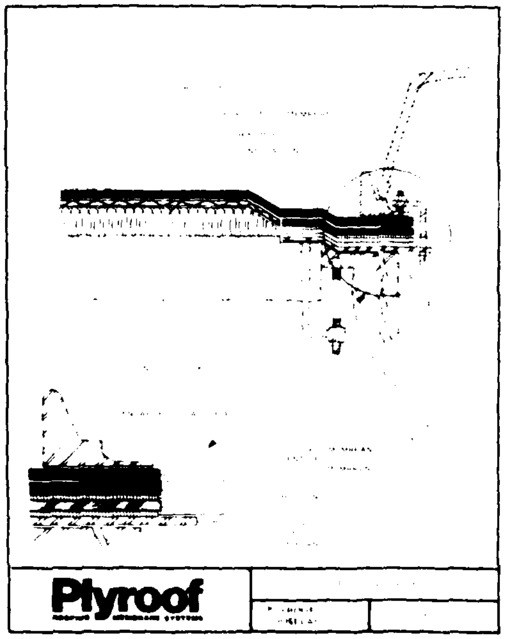


Figure A9. Roof drains.

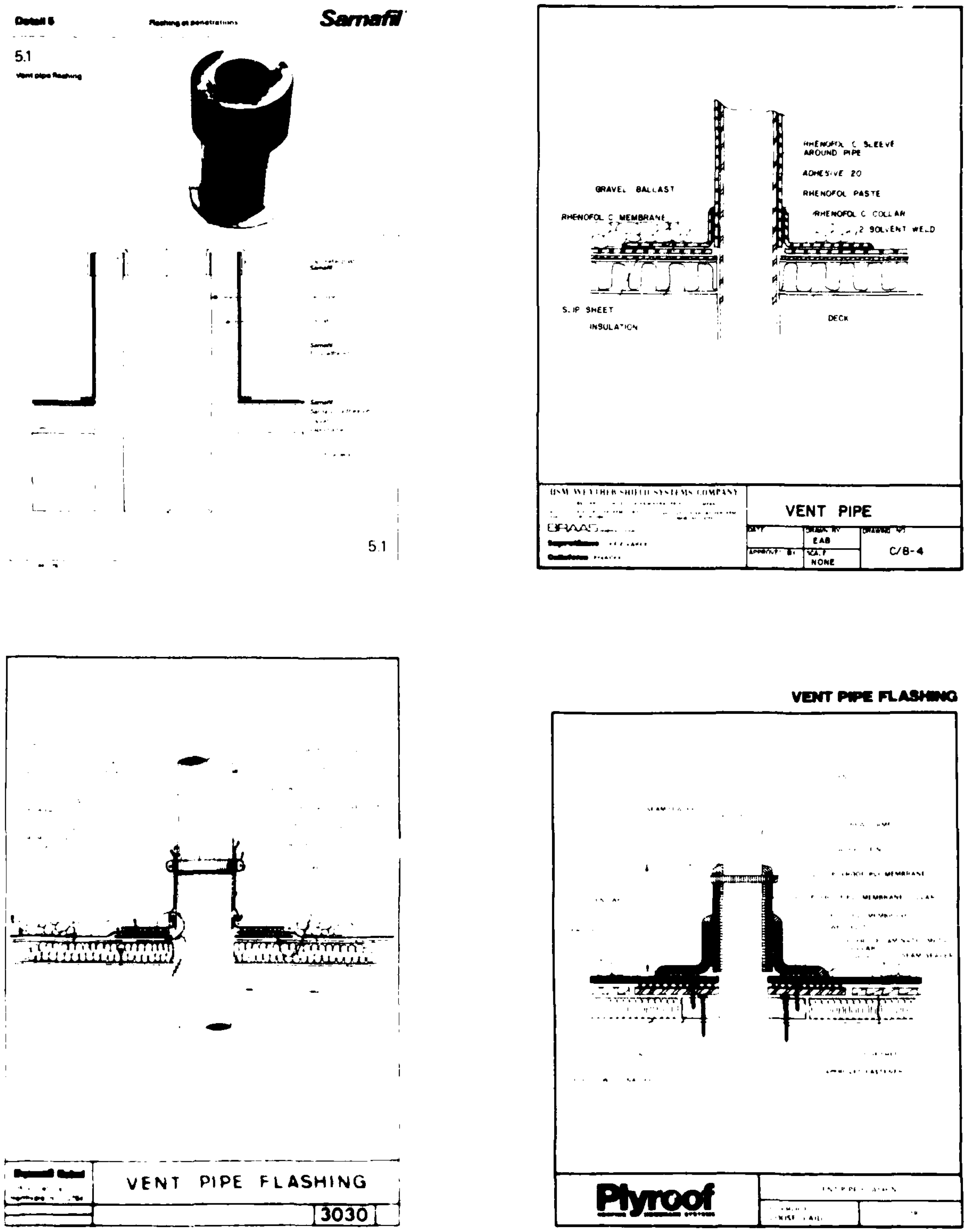
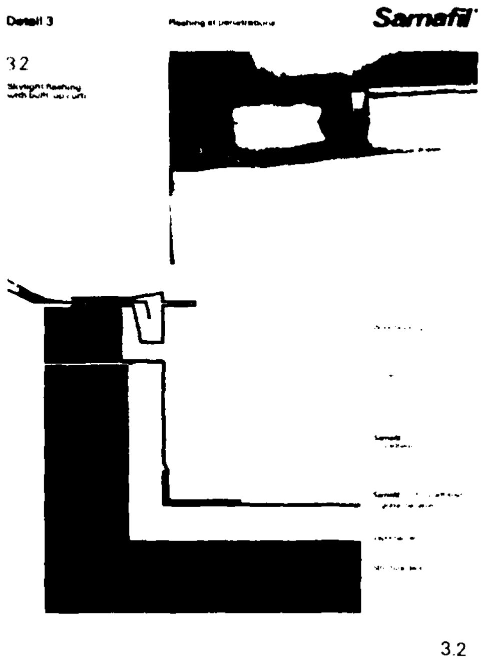
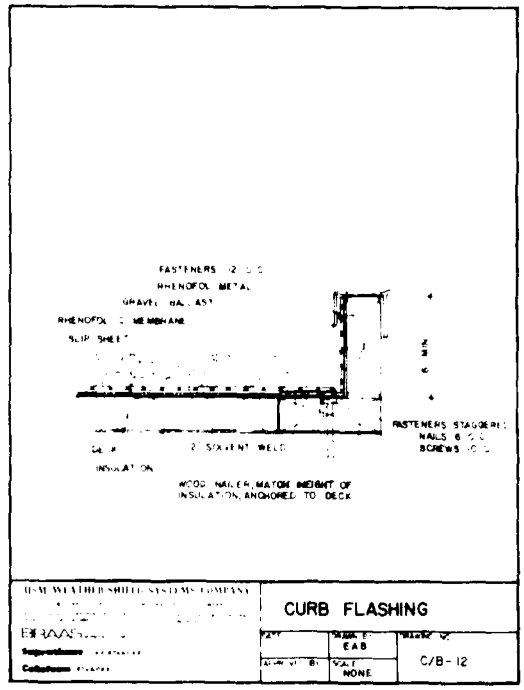
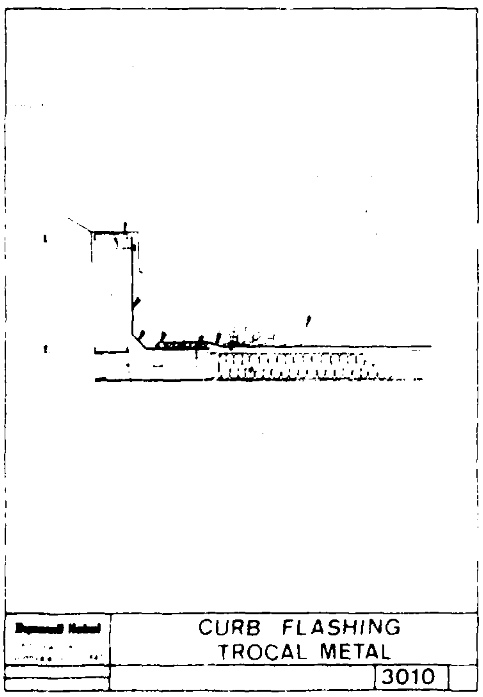


Figure A10. Vent pipes.







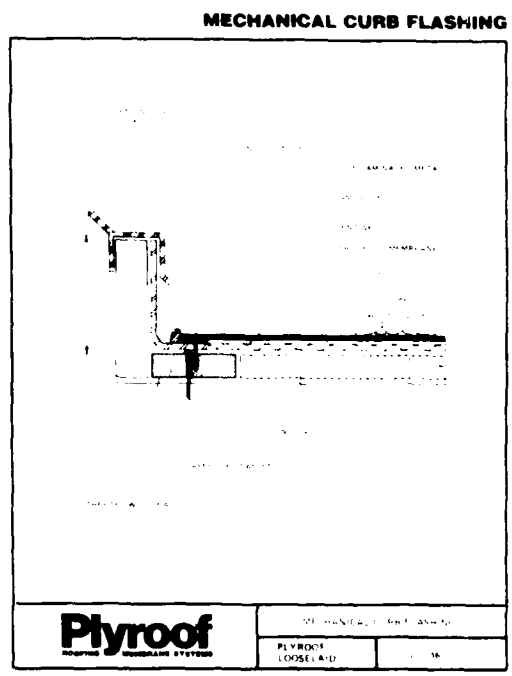
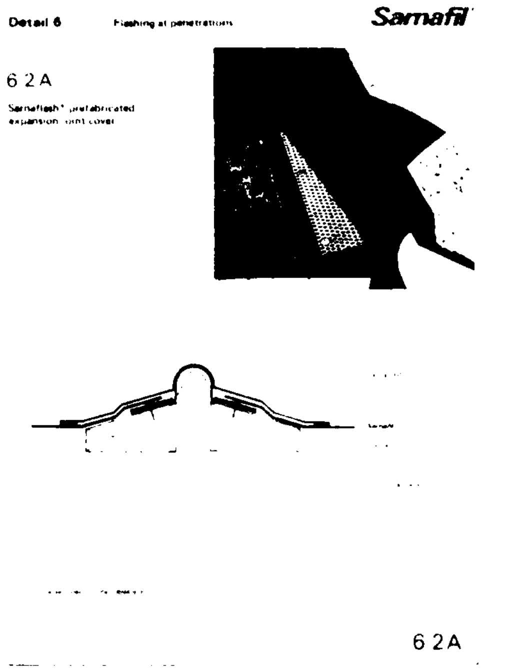
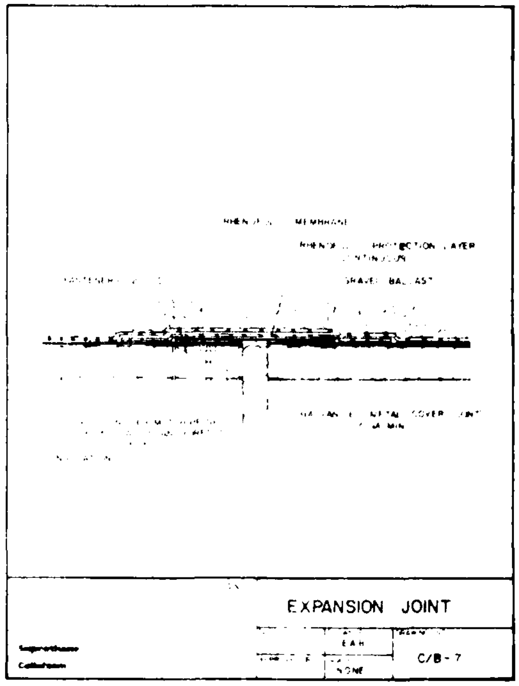
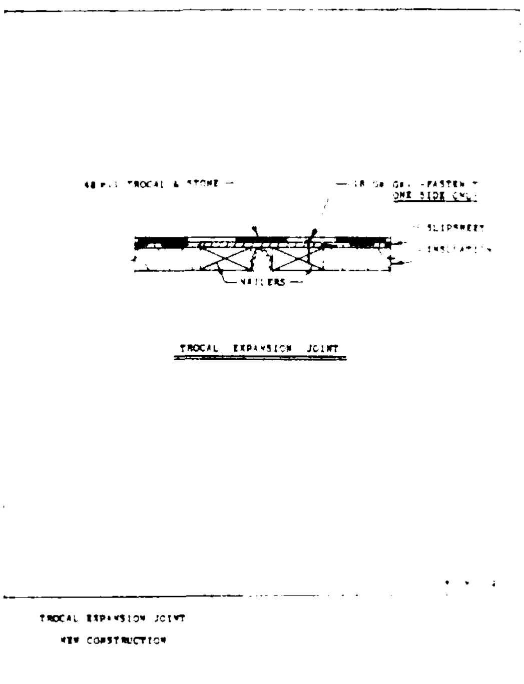


Figure A11. Curb flashings.







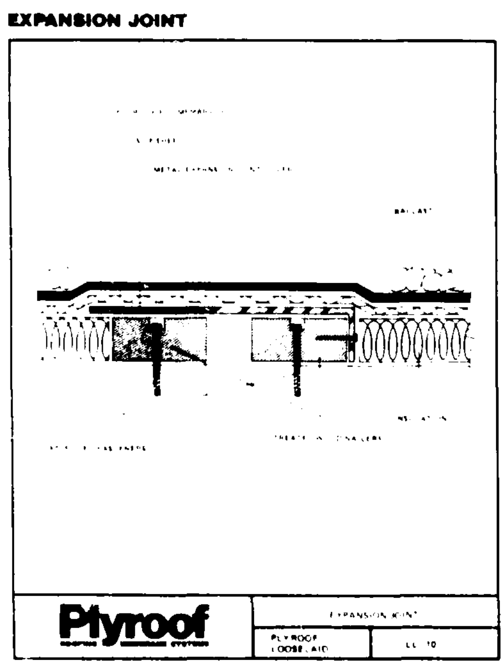
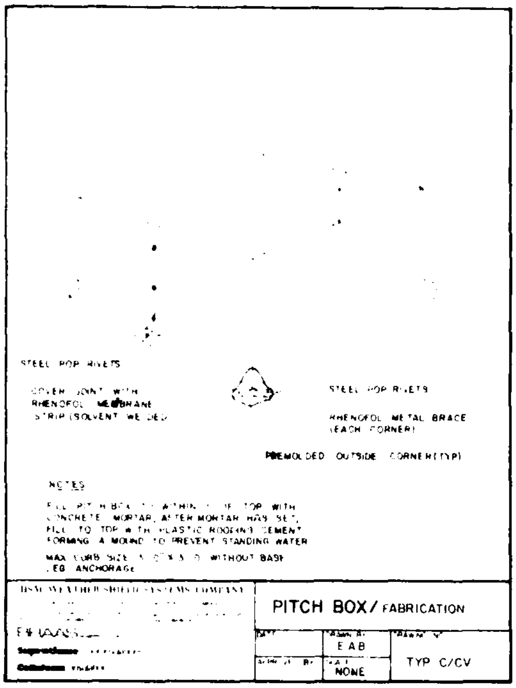
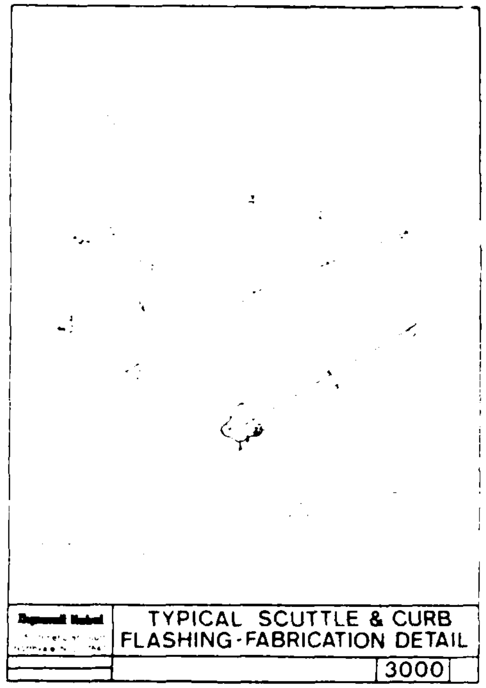
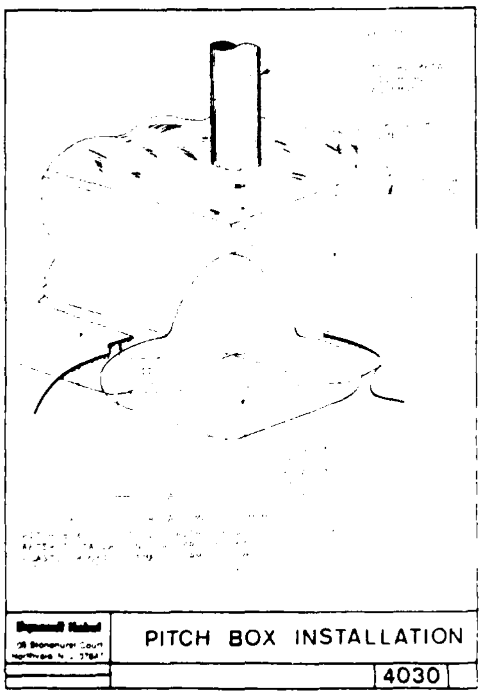


Figure A12. Expansion joints.







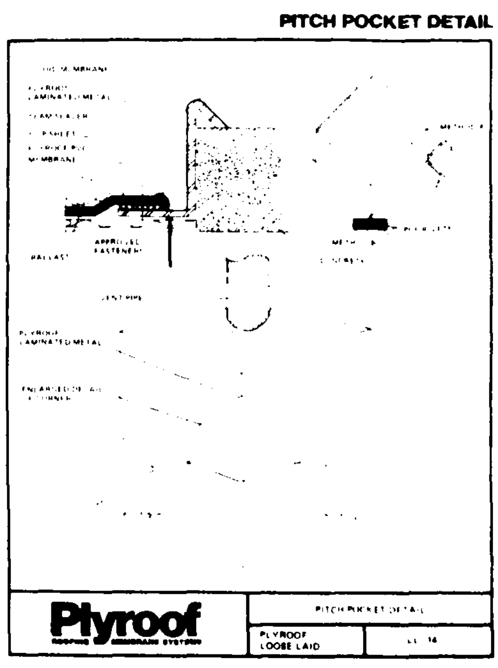
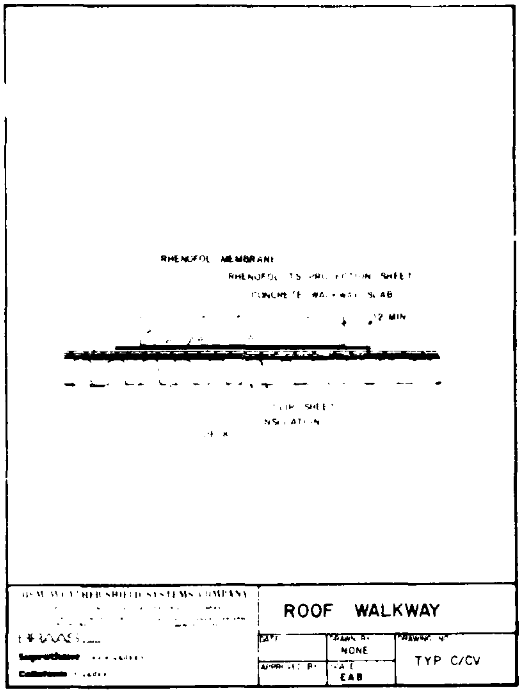
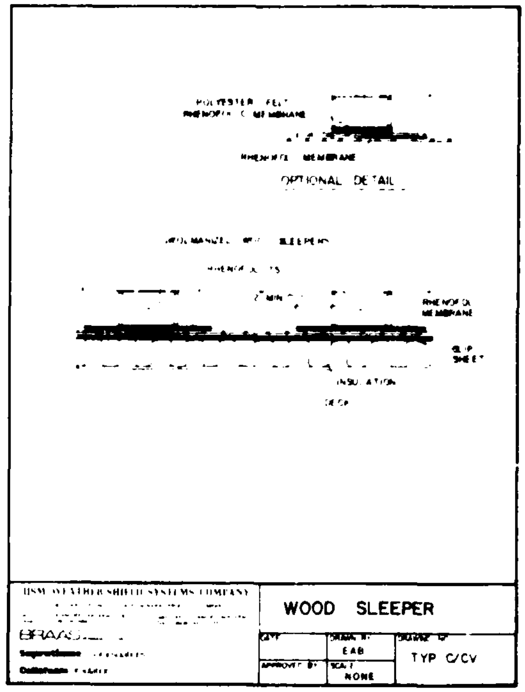
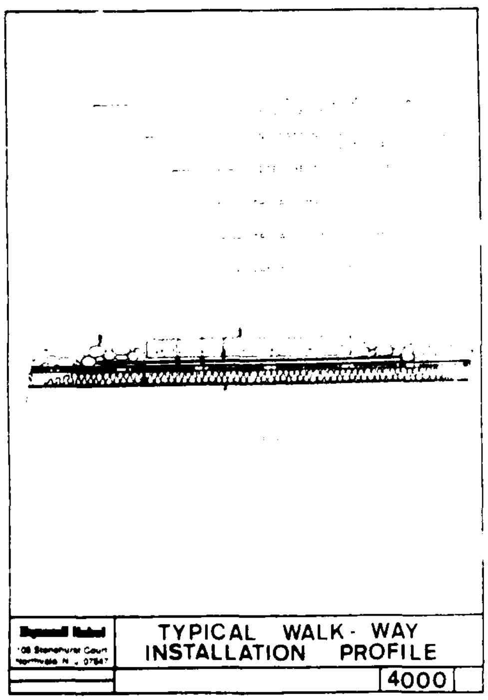


Figure A13. Pitch pockets.







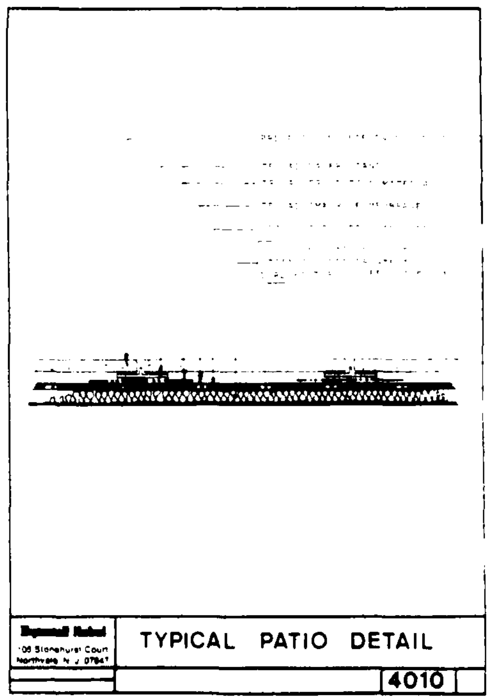
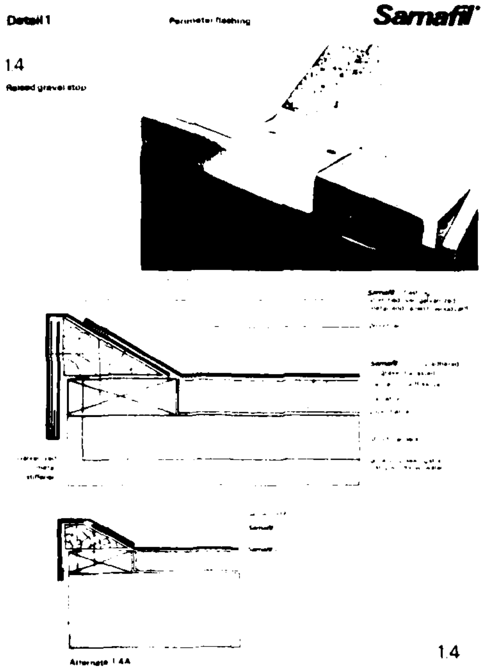
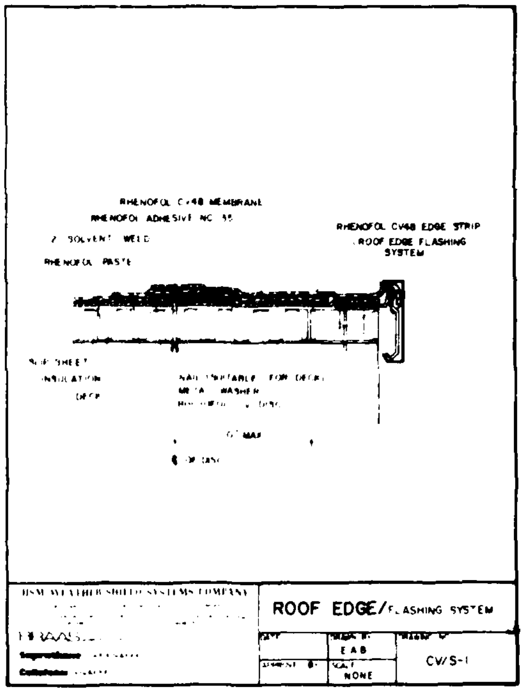
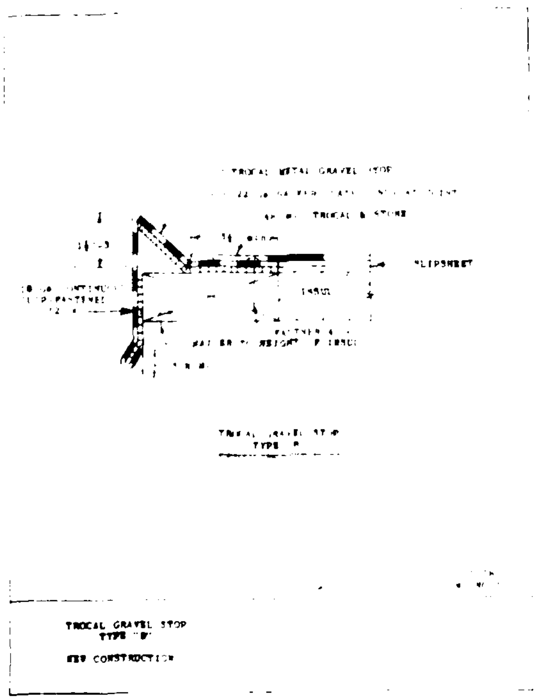


Figure A14. Walkways, patio, and sleepers.







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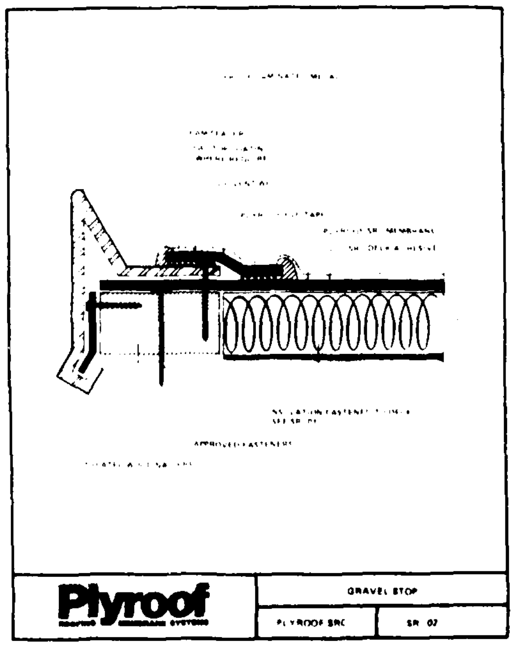
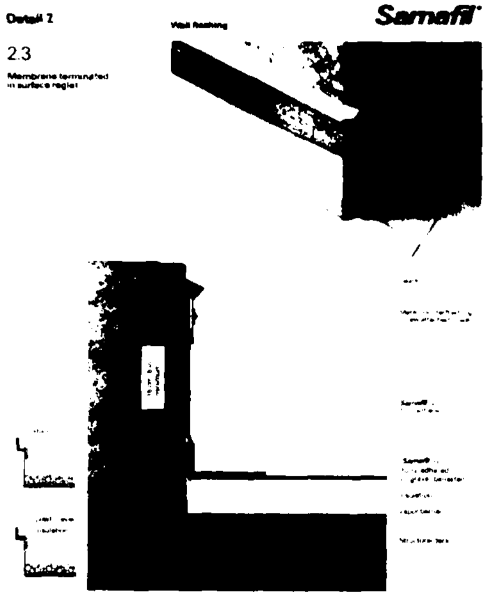


Figure A15. Smooth roof edges.



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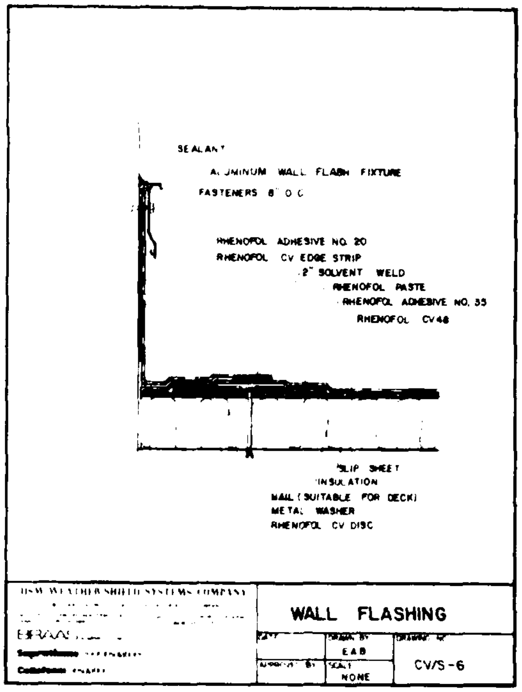
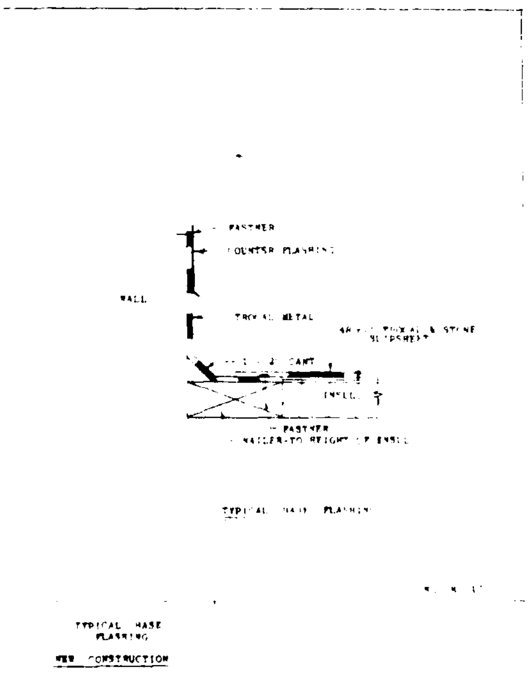




MECHANICAL TERMINATION WALL FLASHING

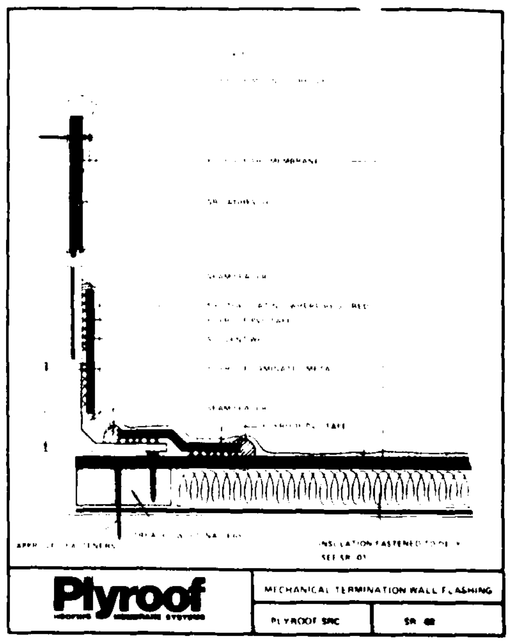
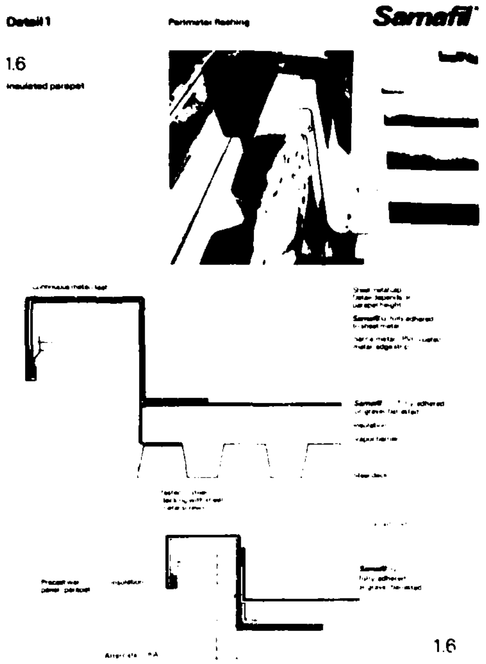
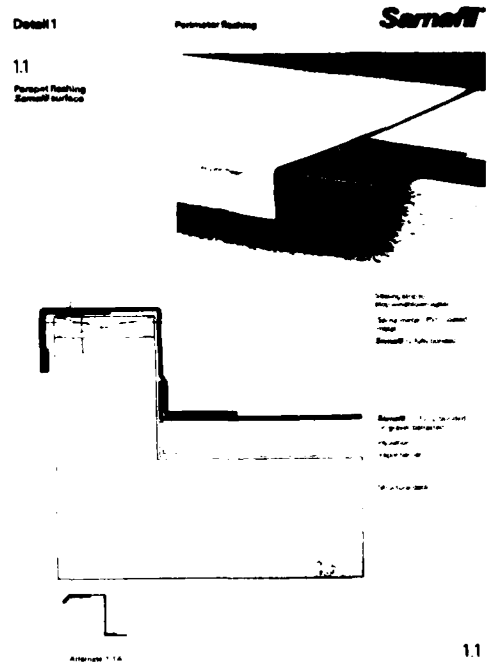


Figure A16. Smooth roof base flashings.





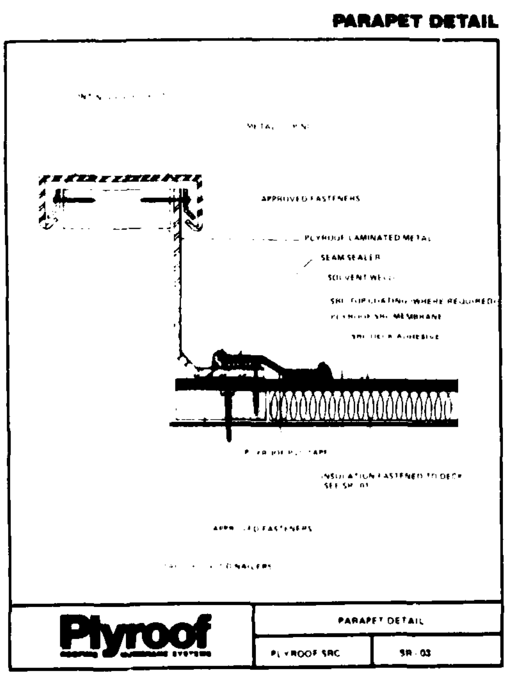


Figure A17. Smooth roof parapet flashings.

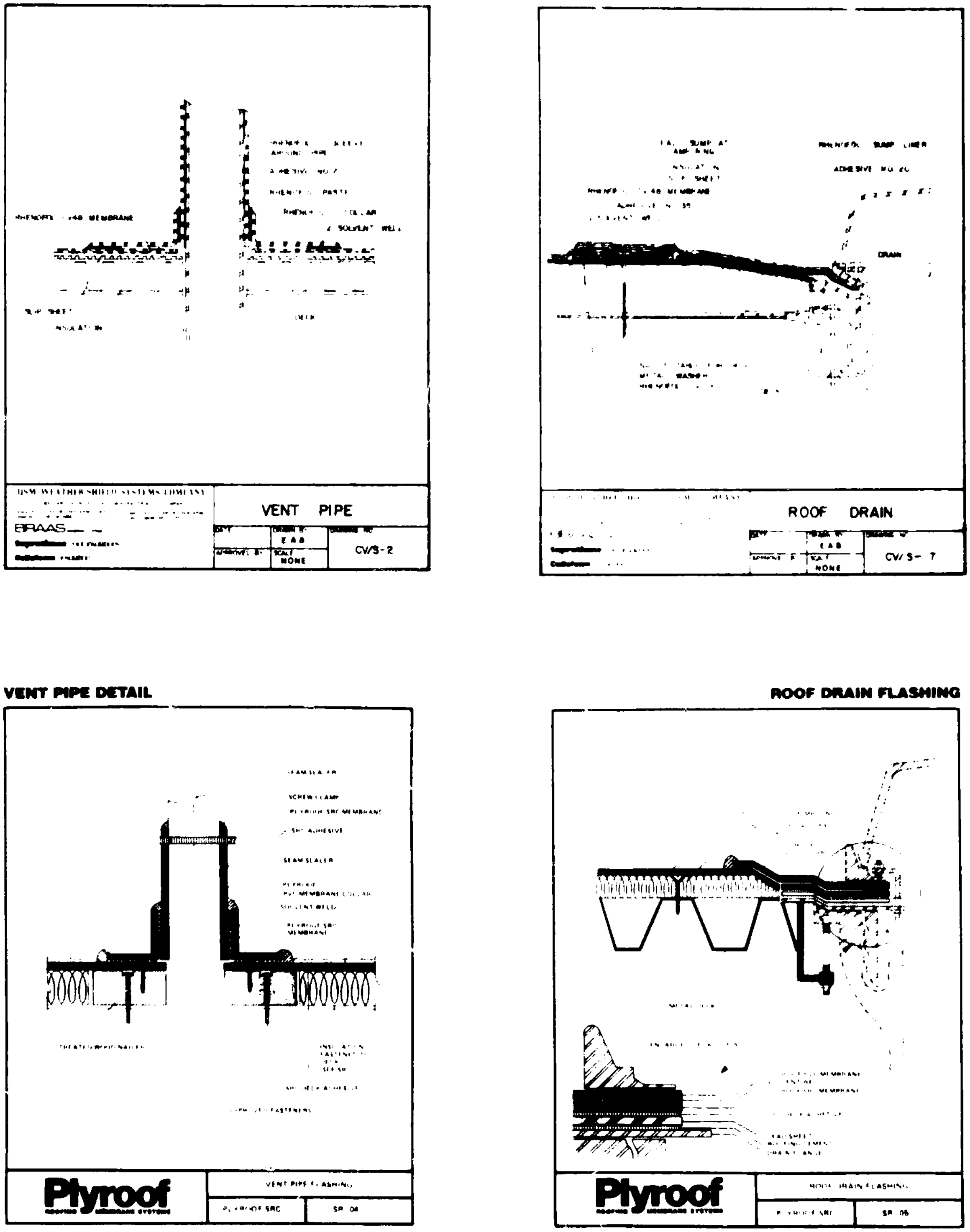
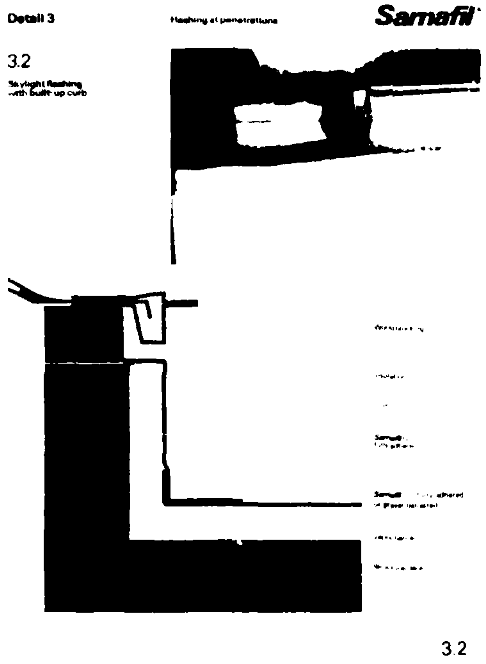
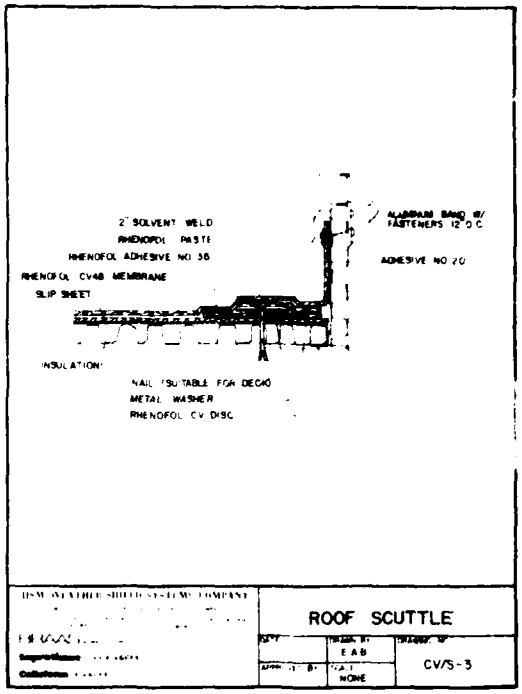
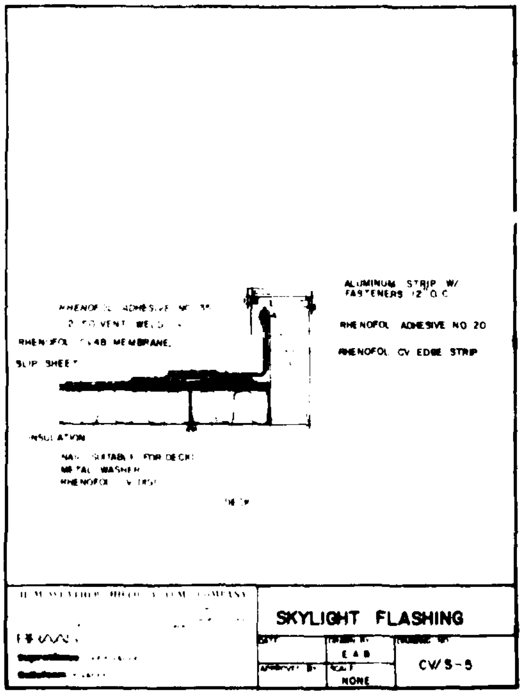


Figure A18. Smooth roof vent pipe and roof drain.







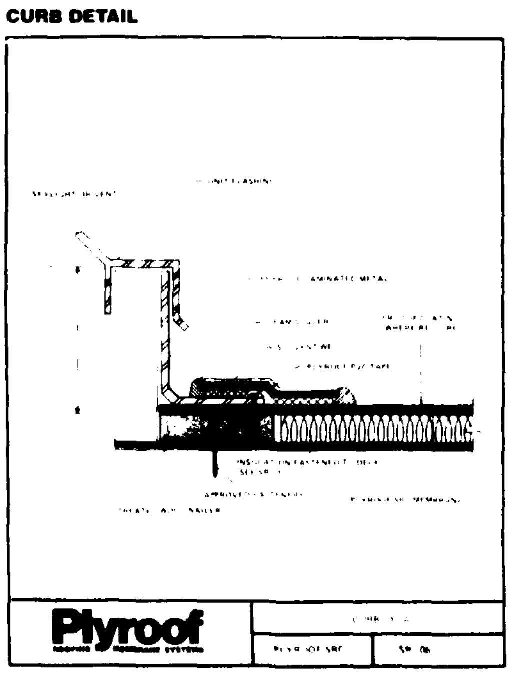
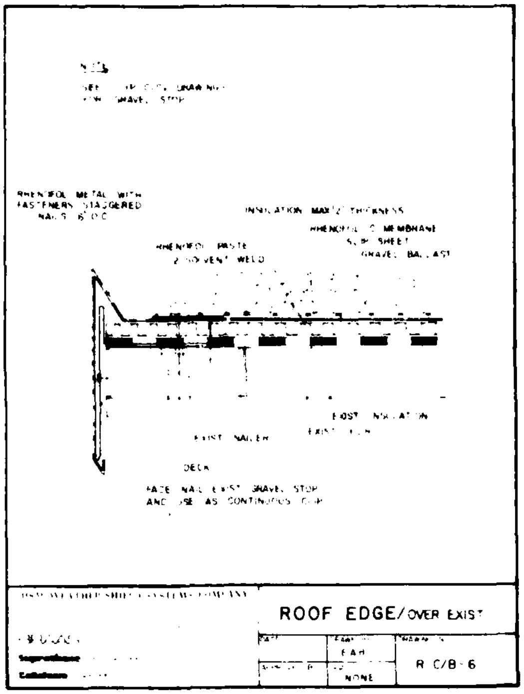
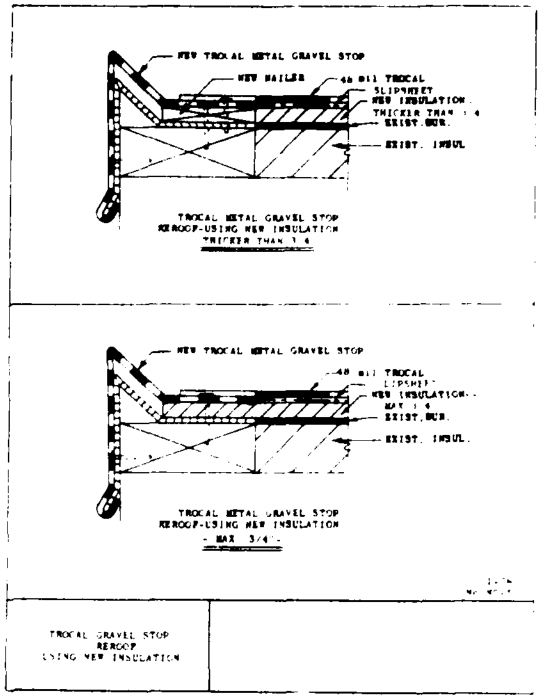


Figure A19. Smooth roof curb flashings.





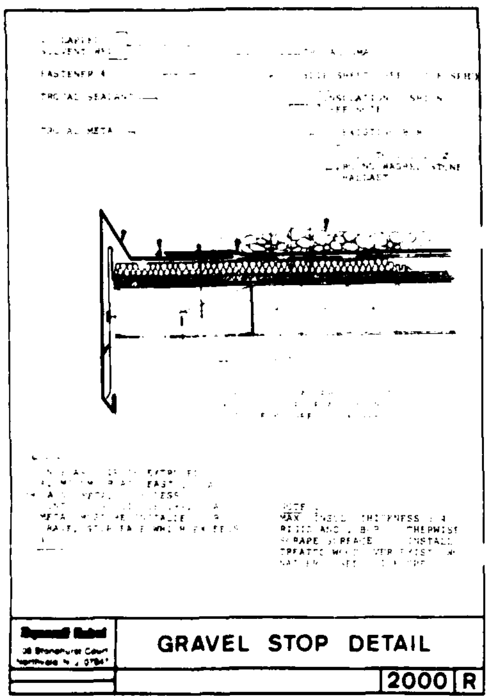
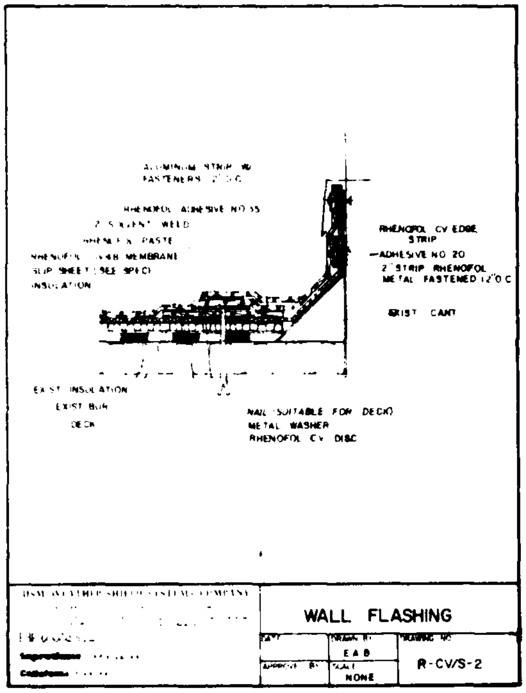
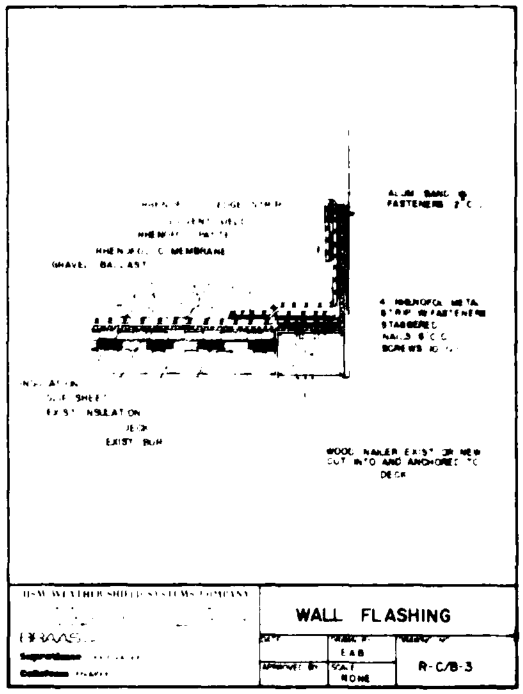
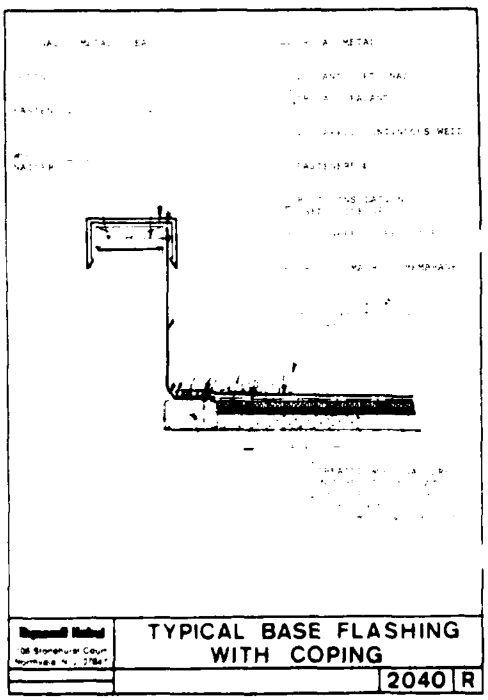


Figure A20. Reroofing gravel stops.







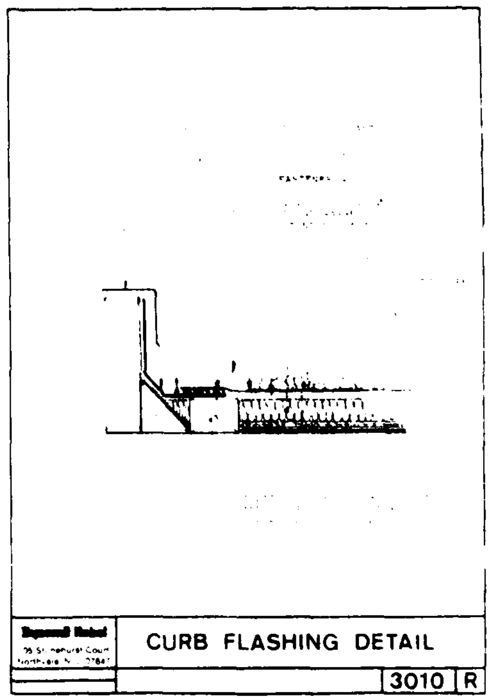


Figure A21. Reroofing base flashings.

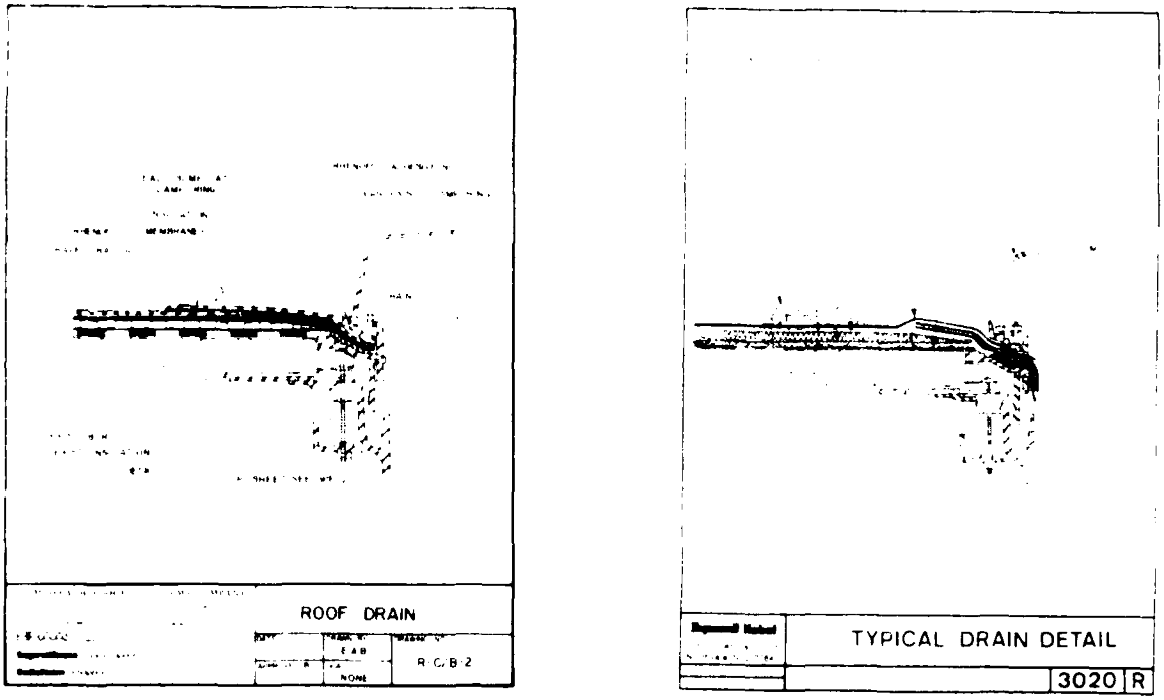


Figure A22. Drain details for reroofing.

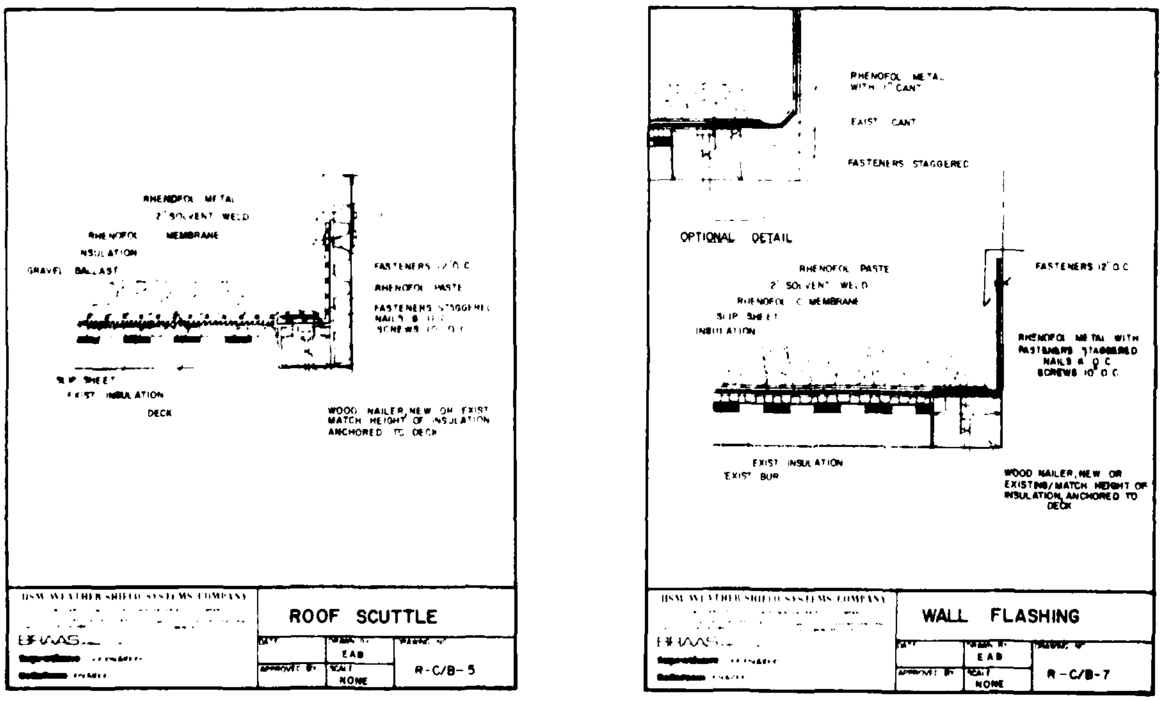


Figure A23. Reroofing base flashings.

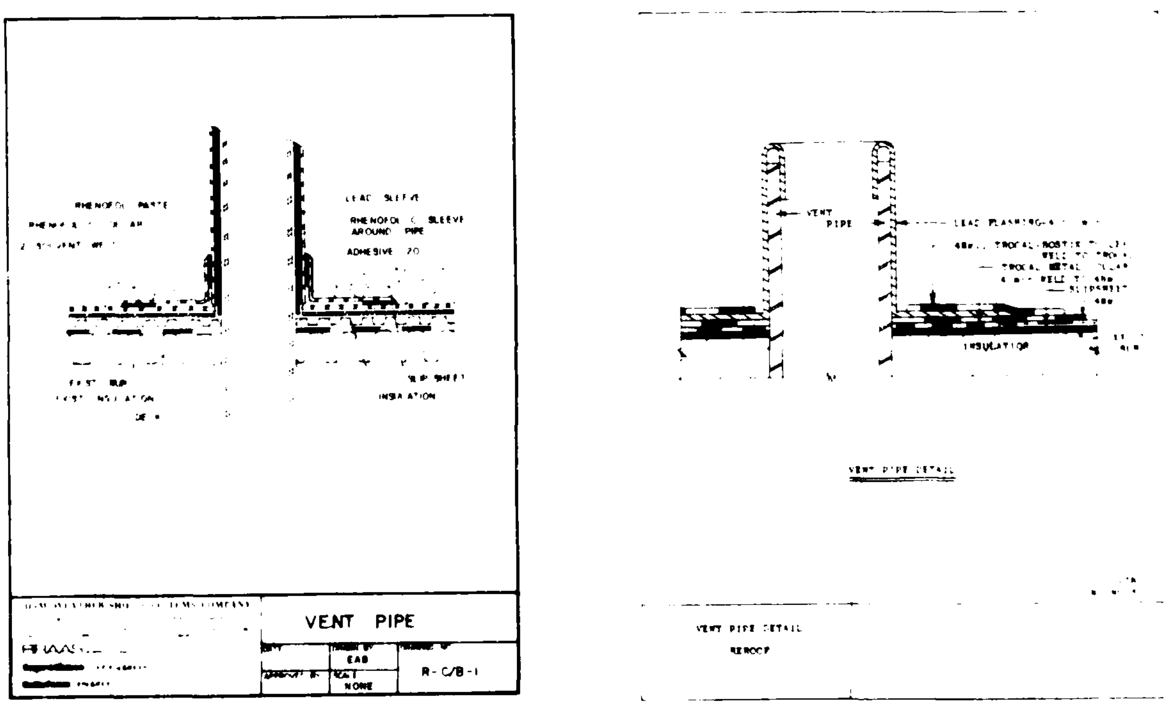


Figure A24. Vent pipe flashing for reroofing.

APPENDIX B:

SUMMARY OF SITE VISITS

Site 1: Warehouse, Eisner Foods, Champaign, IL

1. System: Trocal single-ply membrane, loose-laid and ballasted. Old BUR was removed and new insulation and roofing installed. Area: 7300 sq ft (678 m^2). Approximate cost: $16,000.

2. Age: Installed summer 1977.

3. General appearance: Rectangular roof with gravel stops and gutters on the north and west edges. The east edge has a junction with an old BUR. The south edge is flashed to the upper story wall of an adjacent building. The roof is ballasted by well-rounded rock particles, varying in size from 3/4 to about 3 in. (19 to about 76 mm). The ballast is not distributed uniformly on the roof surface. Penetrations include vent fans, plumbing stacks, and condensing units with associated refrigerant and electric lines. The roof has enough slope to drain well.

4. Observable problems: A layer of mud about 1/8 in. (3.2 mm) thick covers most of the membrane. This indicates the ballast was either not washed or poorly washed before being installed. Three supports for a refrigeration unit were recently placed on the roof and flashed with bituminous cement. This could cause the membrane to harden and crack in a relatively short time. The Trocal metal base flashing along the south edge had been pulled up and away from the insulation surface by membrane shrinkage.

5. Maintenance: There has been no maintenance since installation; no maintenance program is planned.

Site 2: Service and Supply Building, Carle Hospital, Urbana, IL (New Addition)

1. System: Trocal single-ply membrane, loose-laid and ballasted. New installation on addition to original building. Area: 10,200 sq ft (948 m^2). Approximate cost: $24,400.

2. Age: Installed 1977.

3. General appearance: Rectangular roof, bounded on three sides by a parapet. The fourth side has a gravel stop along the edge where the lower, older part of the building continues. The ballast is well-rounded rock particles, varying in size from 3/4 to about 3 in. (19 to about 76 mm). The ballast is distributed fairly uniformly on the roof surface. Penetrations include plumbing vent stacks, roof drains, one exhaust fan, and one fresh-air intake.

4. Observable problems: A layer of mud about 1/4 in. (6.4 mm) thick covers most of the membrane, indicating the ballast was either not washed or poorly washed before installation. Vent stacks were covered with flanged lead

sleeves, as required by local building code. Holes larger in diameter than the stacks were cut in the membrane when it was installed. The membrane was then cemented to the flanges of the sleeves, and the edges sealed with Trocal sealant. The roof has little or no slope, and there is much shallow ponding of water.

5. Maintenance: Some leaks developed about 6 months after installation. These were traced to poor counterflashing at a parapet wall; the counterflashing had not been set into reglets. The counterflashing and base flashing were both removed, and a new Trocal metal base flashing was installed which extended up to the top of the parapet. A cap of PVC was installed on top of the parapet and sealed over the counterflashing. A leak also developed at a roof drain, which was corrected by tightening the drain. There had been no maintenance since then, although a preventive maintenance program is under development.

Site 3: Service and Supply Building, Carle Hospital, Urbana, IL (Old Building)

1. System: Trocal single-ply membrane, loose-laid and ballasted. The loose gravel on the old BUR was removed and the new system was installed at the same time the new building was constructed. Area: 8300 sq ft (770 m^2). Approximate cost: $11,300.

2. Age: Installed 1977.

3. General appearance: Rectangular roof, bounded on three sides by a parapet. The fourth side is the vertical wall of the higher new addition. The ballast is well-rounded rock particles, varying in size from 3/4 to about 3 in. (19 to about 76 mm). The ballast is distributed fairly uniformly on the roof surface. Penetrations include a plumbing vent stack, chase for refrigerant lines, roof drains, and supports for an air-conditioning condenser.

4. Observable problems: A layer of mud about 1/4 in. (6.4 mm) thick covers most of the membrane. This indicates the ballast was not washed or poorly washed before installation. The original lead sleeve was left on the vent pipe, as required by the local building code. In this case, the sleeve was covered with both PVC sheet and the flange. The sheet was cut off just below the top of the stack, cemented to the sleeve, and the edges sealed with Trocal sealant. There is much shallow ponding of water. The Trocal metal base flashing at the new building wall had been pulled up and away from the insulation surface by membrane shrinkage.

5. Maintenance: There have been no leaks in the roof and no maintenance has been necessary. A preventive maintenance program was being developed at the time of the visit.

Site 4: Office Building Roof, Hyster Corp., Danville, IL

1. System: Braas single-ply membrane, loose-laid and ballasted. The old BUR was left in place; only the gravel was removed. New 3/4 in. (19 mm) polystyrene insulation board, slip sheet, and single-ply membrane were installed. Existing counterflashing was reused. Area: 17,000 sq ft (1580 m^2). Approximate cost: $2[illegible],000.

2. Age: Installed June 1978.

3. General appearance: Rectangular roof, bounded on three sides by a parapet and on the fourth by a vertical wall. The ballast is well-rounded rock particles, varying in size from about 3/8 to 2 in. (about 9 to 51 mm). The ballast is distributed fairly uniformly on the roof surface. Penetrations are roof drains, plumbing vent stacks, ventilating fans, and vents for the roof membrane.

4. Observable problems: A layer of mud about 1/8 in. (3.2 mm) thick covers the membrane. This indicates the ballast was not washed or poorly washed before installation. The small size of the particles also indicates that either the ballast was not properly graded or the old gravel from the original BUR was mixed with the new ballast when it was applied. The sheet metal base flashing along the vertical wall has been pulled up and away by membrane shrinkage.

5. Maintenance: None had been necessary during the 17 months between installation and the site visit. The plant engineer felt that the original BUR, whose insulation was wet, had completely dried out since the new roof was installed. No maintenance program is being planned.

Site 5: Combined Barracks and Dining Facility, U.S. Coast Guard Station, Otis AFB, Bourne, MA

1. System: Braas single-ply membrane, loose-laid and ballasted. The old BUR was completely removed from the concrete deck and new insulation and single-ply membrane installed. Area: 15,900 sq ft (1480 m^2). Approximate cost: $45,100.

2. Age: Installed April 1978.

3. General appearance: The single-story dining-galley part of the building is rectangular, with a smaller rectangular clerestory slightly offset north from center. A two-story officers' quarters wing extends south from the southwest corner. A two-story enlisted men's quarters wing extends east from the southeast corner. The ballast is well-rounded rock particles varying in size from 3/4 to about 2 in. (19 to about 51 mm). The ballast is distributed fairly uniformly on the roof surface. Penetrations are plumbing vent stacks, ventilation fans, and two hatches over the galley area.

4. Observable problems: The ballast on this building had apparently been well washed before installation, as no mud was evident anywhere on the roof. The clerestory had no drains and was not sloped to drain, so about 3 in. (76 mm) of water was ponded on it. Although this deck was of concrete, it had the appearance of being dished.

Windows from both living quarters open directly onto the roof over the dining area. The main access door is in the officers wing. This door did not fit its frame and did not close properly. An access ladder extended from the ground to the dining area roof. There was ample evidence that all these roof accesses were well used. The ballast had been completely displaced at each location, leaving bare spots which were 1 sq ft (0.09 m^2) or larger. The dining area roof was well-littered with empty beverage bottles and cans, broken glass, and aluminum can pull tabs.

Because two hatches over the galley offer the only access to refrigeration equipment for the food cold room and freezer, all maintenance traffic must cross the roof. No walkway for this purpose had been installed.

The sheet metal flashing along the residence quarter walls had been pulled up and away by membrane shrinkage.

5. Maintenance: One leak occurred when the exhaust fan on the dining area roof was dropped during installation, breaking the membrane. Another occurred on the clerestory roof when a heat gun used for welding seams was placed on the membrane, melting a hole. Both were repaired by a representative of the manufacturer. There have been no other leaks since then. Maintenance has consisted mainly of picking up the trash at irregular intervals. No attempt has been made to prevent unauthorized access to the roof.

Site 6: Marson's Department Store, Claremont, NH

1. System: Sarnafil single-ply membrane, fully adhered to fiberboard insulation applied over the existing BUR and nailed through to the wood deck. The gravel and all loose material were removed from the BUR before the new insulation was attached. Area: 2848 sq ft (265 m^2). Approximate cost: $7500.

2. Age: Installed December 1975.

3. General appearance: Rectangular roof, bounded on three sides by a parapet and on the fourth by a three-story building. Penetrations are a few small vents and a chimney. The membrane is fully adhered to the substrate, so there is no ballast. The membrane was covered with a thin layer of dirt. (The mechanical fasteners used to attach the fiberboard to the deck and the seams between the fiberboards have caused the membrane to accumulate dirt at different rates at these locations.) Thermal weak links created by the fasteners were evident at the edge of the snow cover where the extra heat loss from the fasteners had melted the snow. Laps at seams are tight. All flashings are tight and secure. Roof drainage is provided by one scupper. Air-conditioning equipment was placed on two planks set on a second layer of PVC. The membrane was flexible at the temperature at the time of inspection (0°F [-18°C]).

4. Observable problems: There were snow and ice on parts of the roof. In some places, they appeared to be 2 in. (50 mm) thick. The ice had several contraction cracks, but none of them appeared to have progressed through the membrane. Several wrinkles were observed in the membrane. These wrinkles were apparently caused by shear forces. They suggest that some membrane shrinkage has occurred. However, no dislocation of any flashing was observed. The driveway alongside the building is a convenient walkway for individuals who apparently throw bottles and other objects up onto the roof. Several pieces of broken glass were observed, along with cans, old pipes, and other trash. The scupper is blocked by debris.

5. Maintenance: Other than occasional removal of the trash, none has ever been needed or performed. A suggestion was made to the owner that a screen be installed at the scupper.

Site 7: University of Illinois Employees Credit Union, Champaign, IL

1. System: Trocal single-ply membrane, loose-laid and ballasted. This is a new installation on a new building. Area: 12,200 sq ft (1130 m^2). Approximate cost: $49,000.

2. Age: Installed February 1980.

3. General appearance: Rectangular roof, bounded on all four sides by a low stub parapet. Penetrations include roof drains, plumbing vent stacks, two access hatches, support curbs for air-conditioning equipment, and 22 I-beam supports for screens to hide all the equipment from view.

The building is designed so that a second story can be added in the future. The present roof is a steel roof deck, 3/4-in. (19-mm) fiberboard fastened with screws, No. 43 base sheet single-ply in asphalt, loose-laid tapered polystyrene insulation faced with kraft paper surface factory bonded to it, PVC membrane loose-laid, and 3/4 to 1-1/2 in. (19 to 38 mm) gravel. The drains are made of lead and all vents are covered with sheet lead. The PVC membrane is bonded to the lead and sealed.

4. Observable problems: None as yet; the roof was being installed when the site visit was made. The gravel did not appear to be washed. There was a lot of dust created when the gravel was transferred from the delivery truck to the lift truck and from the lift truck to the buggies. The transfer area on the roof was covered with a heavy silt.

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Omaha
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North Pacific
ATTN: Laboratory

Facilities Engineer
Ft. Benning, GA 31905
ATTN: ATZB-FE-EP
ATTN: ATZB-FE-BG

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AFESC/PRT
Tyndall AFB, FL 32403

Peterson AFB, CO 80914
[illegible]

Tinker AFB, OK 73145
[illegible]

Patrick AFB, FL [illegible]
[illegible]

McClellan AFB, CA 95652
[illegible]

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